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Effectiveness of Weathergrooves in Weatherboard Cladding

J. C. BURGESS*

An experimental study on the sizing of weathergrooves in horizontal weatherboard cladding of buildings is presented, including a study on the effects of surface finish on capillary rise. Conclusions are drawn for the size of grooves, and surface finishes which will retard the capillary rise of water through horizontal lap joints in weatherboarding, and also prevent water ingress under wind pressure.

1. NOMENCLATURE

- $\gamma_{l\text{-}v}$ Surface tension of liquid-vapour interface [N/m]
- $\gamma_{v\text{-}s}$ Surface tension of vapour-solid interface [N/m]
- $\gamma_{l\text{-}s}$ Surface tension of liquid-solid interface [N/m]
- γ_i Resultant tension vector on surface i [N/m]
- θ Contact angle of liquid on a solid surface [°]
- θ_i Contact angle on surface i [°]
- h Height of rise of water column above free liquid surface [m]
- d Separation distance of plates, or width of joint [m]
- l Length of joint [m]
- x Depth of weathergroove [m]
- y Width of weathergroove [m]
- ρ Density of water [kg/m^3]
- g Acceleration due to gravity [m/s^2]
- $\mathcal{R}$ Wenzel's Roughness factor
- A_i Adhesion tension on surface i ($=\gamma_{l-v}\cos\theta$) [N/m]
- Γ Capillary pressure [N/m^2]
- V Volume of water in joint [m^3]
- F_b Breaching force used in derivation of breaching pressure [N]
- P_{tot} Total pressure on water in joint [N/m^2]
- P_b Pressure required to breach a weathergroove from the lower groove edge [N/m^2]
- P_{app} Applied pressure, above atmospheric pressure [N/m^2]
- $\approx$ Approximately equal to

2. INTRODUCTION

THE PROBLEM of rain entry into buildings has been around since buildings themselves, and the various mechanisms of weather penetration have long been the subject of study. Rain penetration through horizontal lap joints in timber claddings, was historically solved by milling horizontal grooves into the adjacent faces of the lapped joint. This appears to be an intuitive use of weathergrooves in weatherboard-type claddings, as studies exist on the effect of horizontal joint sizing [1], but there is no record of studies concerning the physical mechanisms of weathergroove breaching, or of groove size and timber surface effects.

A wide range of sizes of weathergrooves in building cladding materials are now seen, and there are no existing guidelines for just how big these grooves should be, or their limitations when used in new materials. Weathergrooves have also been omitted entirely from some new weatherboard-type systems, due to the materials thickness being too small to accommodate weathergrooves without risk of breakage during transport, handling, or installation.

This study was initiated to clarify the physics of weathergroove performance in horizontal weatherboard cladding lap joints, and to derive dimensions of useful groove sizes. In this paper an equation for the capillary rise of liquid in a horizontal lap joint is derived from considerations of surface tension, and consequent interface behaviour. Contact angles are utilized to characterize the varying height of capillary water rise in these joints, and an equation of breaching pressure is introduced. The behaviour of the liquid-vapour interface travelling through a weathergroove is explained, and then the theory is evaluated in the experimental section, where measurements of breaching, breaching pressure, and contact angles are made. Data are taken in acrylic-plastic and wooden joints. Breaching of weathergrooves by capillary pressure is treated separately from the breaching caused by wind pressure or pressure differences.

3. THEORY

3.1. *Surface Tension*

For a drop of liquid water on a solid surface, in equilibrium with water vapour, surface tensions arise from the asymmetrical distribution of inter-molecular attractions at the boundaries between the three phases, due to the polarity of water molecules and van der Waals' forces [2]. Water is a polar molecule, so a drop of water may 'stick' selectively to parts of a surface of a joint with polar, or electronegative characteristics [3]. This can cause erratic, or even zero interface movement [4].

3.2. *Contact Angles*

If a smooth clean plate dips vertically into a liquid, then a definite shape termed the capillary curve is assumed by

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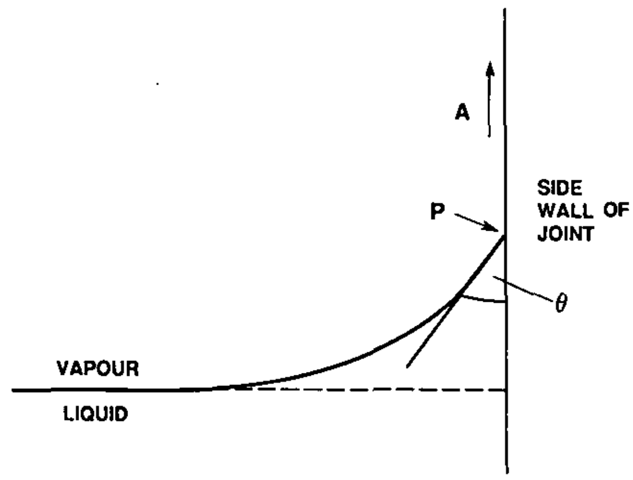

Fig. 1. The capillary curve.

the surface of the liquid close to the plate. See Fig. 1. Here a point P, marks the triple interface, where vapour and liquid phases meet solid, for example at one vertical side of a horizontal weatherboard lap joint, where A is the adhesion tension and θ indicates the contact angle.

The angle of contact of a liquid on a solid surface can range from zero to 180 degrees, [5] although only angles between zero and 100 degrees are common for water on painted or primed surfaces. An equation for the height h, of capillary rise in a horizontal joint gap with parallel vertical sides, can be derived by considering the forces maintaining equilibrium of the elevated liquid. See equation (1). This is given by Newman and Searle [6] after assuming that the two vertical surfaces of the joint are identical as:

$$h = \frac{2\gamma_{l\text{-}v}\cos\theta}{d\rho g} - \frac{d}{(8-2\pi)}. \tag{1}$$

Different surfaces can display widely varying contact angles. Figure 2 displays the theoretical variation of height of capillary rise of water, with reciprocal joint width $1/d$, and varying contact angle θ. This assumes that the solid surface is perfectly smooth, which rarely occurs in practice, as Wenzel's roughness factor $\mathcal{R}$ is involved [7]. This is defined as $\mathcal{R}$ = actual surface area/geometric surface area. $\mathcal{R}$ is assumed to be 1.0 for acrylic-plastic, and for primed wood. This factor was not separated in this work, so it should be noted that $A\mathcal{R}$ is actually utilized instead of A, and likewise $\Gamma\mathcal{R}$, instead of Γ.

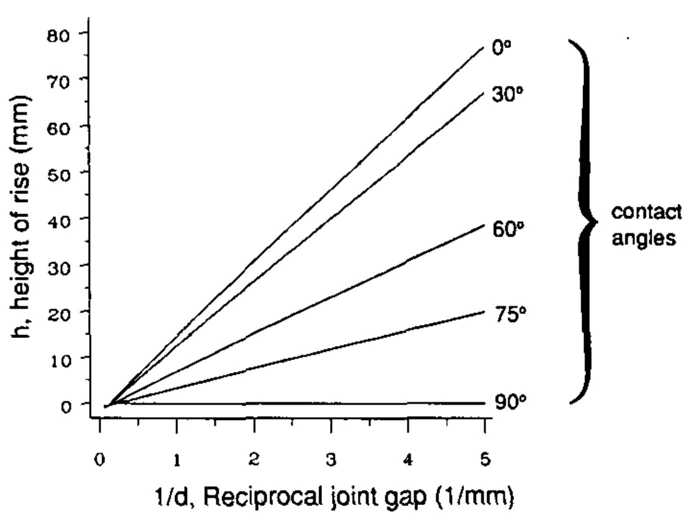

Fig. 2. Height of capillary rise of water vs reciprocal joint gap, for various contact angles.

3.3. *Weathergrooves*

In the situation where horizontal weatherboards are used as the cladding system for a building, water from surface run-off collects at the lower edge of the boards, which ensures that over a period of rain there is a near continuous supply of water to allow capillary action to occur in the underlying joint.

The capillary force per square metre acting in such a weatherboard joint, Γ, can be obtained from equation (1) with the allowance for a different contact angle on each side of the joint, θ_1 and θ_2 [8] as the 'capillary pressure' given in equation (2).

$$\Gamma = \frac{\gamma_{l\text{-}v}(\cos\theta_1 + \cos\theta_2)}{d} - \frac{d\rho g}{(8-2\pi)}. \tag{2}$$

The resultant upward (or downward) pressure acting on the liquid-vapour interface in the joint gap, is then given by the sum of the capillary pressure, Γ, applied pressure, P_{app}, and the pressure due to the effect of gravity, ρgh, as in equation (3).

$$P_{tot} = \Gamma + P_{app} - \rho gh. \tag{3}$$

3.4. *Weathergroove Dynamics*

As liquid rises in a uniformly tight lap-joint, P_{tot} falls as h increases, and an equilibrium is eventually established when $\rho gh = \Gamma + P_{app}$ in equation (3). As can be seen in Figs 3.1–3.5, (which correspond to points A–E in Fig. 4), the essential factor exploited by a weathergroove is that when liquid reaches the stage of Fig. 3.2 (and point B in Fig. 4), the contribution to Γ from A_1 becomes zero (or negative), and the effective joint width, d, becomes larger which reduces the contribution to Γ from A_2. See equation (2). This also causes P_{tot} to fall, by equation (3). An equilibrium may now be reached at a lower point in the joint than would be expected in a uniformly wide joint. A parameter P_b can now be derived (see Appendix A) to calculate the total pressure required to breach a weathergroove of specific dimensions x and y, and at a certain height h, above the free water surface.

So P_{tot} (total pressure) in equation (3) must have a value at the groove lower edge that exceeds P_b, (breaching pressure) if the weathergroove is to be breached.

$$P_b = \frac{\gamma_{l\text{-}v} - 3\gamma_{l\text{-}v}\cos\theta + \rho gy(x+d)}{d}. \tag{4}$$

If the total pressure P_{tot} does not exceed the breaching pressure P_b, then the meniscus will not breach the groove. But, increasing P_{app} (caused by wind) can increase P_{tot} enough to exceed P_b, and allow breaching to occur.

Figure 4 shows a calculated example of the resultant pressure on the system P_{tot}, for a 0.4 mm joint gap, and a 3.0 mm × 2.5 mm weathergroove. In this case P_{tot} is initially less than P_b. For breaching to occur here, a pulsed pressure increase, equal to at least 200 Pa, would be needed to drive P_{tot} positive. Then the meniscus can proceed from h = 10 to a height of h = 12.5 mm, where the total pressure P_{tot} rises above zero, allowing capillary rise to continue up to a height of 21 mm. Due to the minima on the graph in Fig. 4, the meniscus is usually

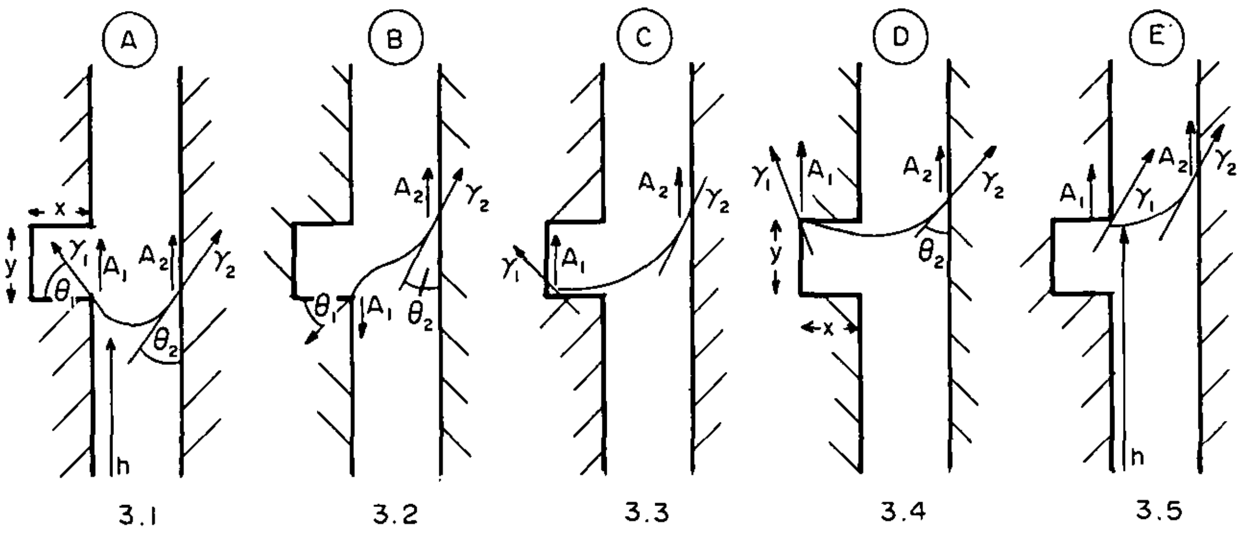

Fig. 3. Meniscus behaviour at a weathergroove.

observed at point A, or above point E, and seldom will an equilibrium exist at the intermediate points as the joint gap *d*, is too large.

When two facing grooves are present in a joint, (one in each side), a similar analysis is possible. Here the grooves in any non-porous material can not be breached by capillary pressure alone, as Γ becomes negative at the bottom edge of the grooves, and additional wind pressure, P_{app}, is required to cause breaching.

4. EXPERIMENTAL

4.1. *Experiments*

A weatherboard cladding horizontal joint, with a weathergroove, was simulated in the laboratory as illustrated in Fig. 5 and the following experiments performed:

1. The effect of groove size on capillary rise was investigated in primed and un-primed wood. See Section 5.1. (Common New Zealand building practice is for the manufacturer to pre-prime weatherboards.)
2. Magnitudes of P_{app} required to breach a groove in primed timber were measured, from pressure versus height hysteresis plots for various configurations of groove and joint dimensions. See Section 5.2.
3. Magnitudes of P_{app} required to breach a groove in an acrylic-plastic to acrylic-plastic and an acrylic-plastic to wood joint, were measured. See Section 5.3.
4. Contact angle measurements of water drops on various surfaces were made to establish the range of contact angles likely in lap joints, and also to determine whether wooden joints can be simulated by acrylic-plastic. See Section 5.4.

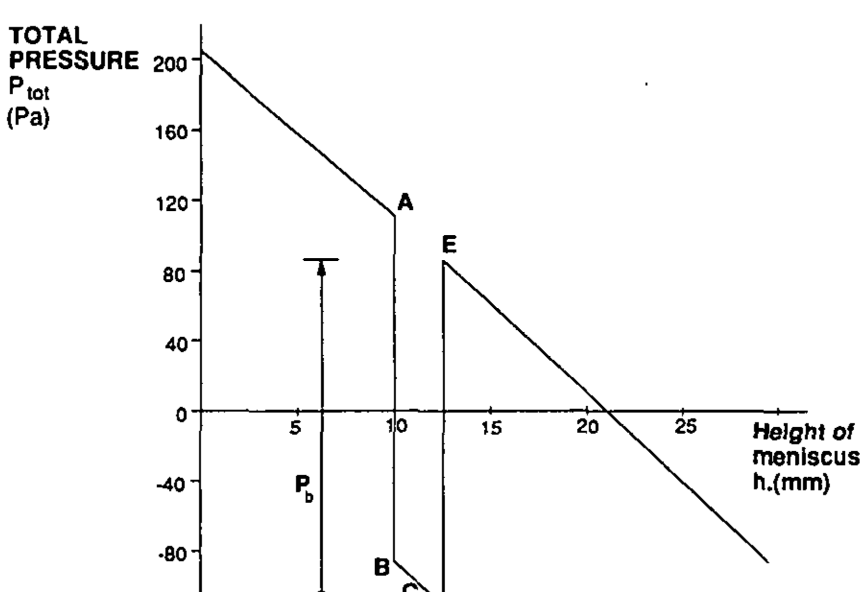

Fig. 4. Graph of P_{tot} for a joint 0.4 mm wide. An applied pressure exceeding P_b will provide enough pressure to allow breaching, and prevent the graph going negative. Weathergroove is 3.0 mm deep × 2.5 mm, between h = 10 and 12.5 mm.

4.2. *Techniques*

Experiments were performed in a part filled water-tank, (see Fig. 5) which had a simulated weatherboard joint mounted in it, and could be pressurized. A slight salinity provided electrical conductivity, yet did not affect the capillarity, as both surface tension and density are increased by increased salinity with cancelling effects. A resistive probe was developed for the first experiments, where a fine nichrome wire was wound on a thin, insulated former and inserted vertically into the joint under test. The probe was calibrated so that as ionized water in the joint rose, it altered the ground point, and the electrical resistance varied linearly with height of rise. 'Groove edge probes' were also inserted into the joint to register precisely when the liquid reached the groove edges. The contact angle of water on solid surfaces was achieved by photographing a sessile drop under magnification [9]. Although this method is only accurate to 8%, the wide variation of joints and surface roughness did not warrant any more accurate study.

5. RESULTS

5.1. *Sizing of Grooves*

Tight wooden joints with weathergrooves were tested for capillary rise in the absence of an applied pressure, with the weathergroove dimension *y*, varying from zero up to a width of 10 mm, and *x* from zero to a depth of 7 mm. The joint gap *d* was varied from zero (joint screwed together) to 1.65 mm, with the height *h* of the groove above the free liquid surface also a variable. The lower useful limit to the width *y* of a weathergroove is obtained when the meniscus bulge in Fig. 3.2 contacts the upper edge of the weathergroove, and breaching is able to occur without the meniscus progressing through the groove. This dimension was found to be about one millimetre. Several trials of each groove and joint gap size were performed, and it was found that increasing the groove

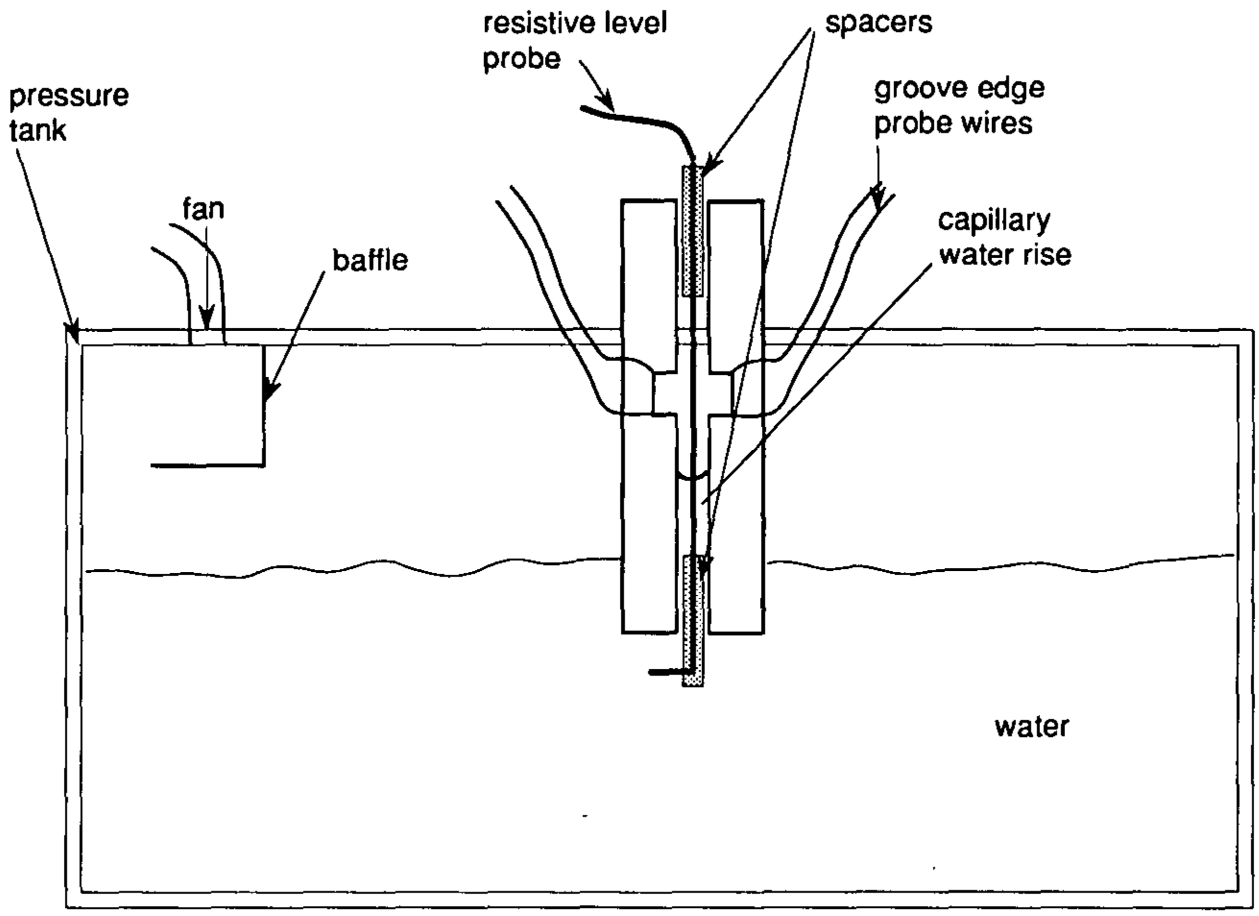

Fig. 5. Laboratory pressure tank and sample joint.

height above the water surface, decreased the occurrence of breaching, as was expected from equation (3). Results were averaged, and are presented in Table 1, and in Fig. 6. Here (and in Fig. 6) an effectiveness of 1.0 is defined as $P_{tot} < P_b$ at the groove lower edge, which prevents any capillary rise, and an effectiveness of zero as $P_{tot} > P_b$ which allows breaching to occur. Intermediate values where $P_{tot} \approx P_b$ are calculated by averaging the ones and zeros of repeated experiments, when a groove would not consistently prevent (or permit) breaching.

It can be seen from the experimental results in Table 1, and Fig. 6, that no single groove in an unprimed wooden joint can be made large enough to prevent some water eventually penetrating through the groove by capillarity, unless the groove is above the height of maximum capillary rise. This is attributed to the fact that unprimed wood is porous, allowing water to travel upwards in micro-capillaries [10] formed by the fibres of the wooden surface. This water can rise to heights above that expected for the bulk water in the joint, as given by equation (1), due to the distance d between the wood fibres being in the order of a micron. But, this means that the effective contact angle of the bulk water in the joint gap will then approach zero, which increases the height of possible capillary rise of bulk water in the joint, by equation (1), and so breaching of the groove can eventuate due to the micro-capillarity in the surface layers of the wood.

Two facing grooves in a bare wooden joint prevented capillary water rise above the groove, when the groove had dimensions greater than a width of 3.5 mm, by a depth of 4.0 mm, and was set at $h = 30$ mm above the free water surface. In the case of a freshly primed wooden surface, depending on the contact angle made, one groove will suffice to prevent any capillary rise, again provided that the groove sizing is larger than 3.5 mm wide × 3.5 mm deep. Joints with freshly primed wooden surfaces with two facing grooves 10 mm above the water level, prevented capillary water rise in all grooves tested.

Table 1. Effectiveness of weathergrooves. Effective is where $P_{tot} < P_b$, denoted by a 1, not effective is where $P_{tot} > P_b$, denoted by a 0. Other values occur when $P_{tot} \approx P_b$. A '2' in the 'number of grooves' column, indicates facing grooves, one in each side of the joint

Material	No. of grooves	Groove size, width × depth (mm)						
		10×4	8×3	3.3×7	3.3×5	3.3×3	3.3×2.4	3×1.6
Plywood	1	0	0	0	0	0	0	0
	2	1	1	1	1	0.5	0.8	0
Primed	1	1	1	1	1	1	1	0.2
Ply	2	1	1	1	1	1	1	1
Acrylic-plastic	1	1	1	1	1	1	1	0.6
	2	1	1	1	1	1	1	1

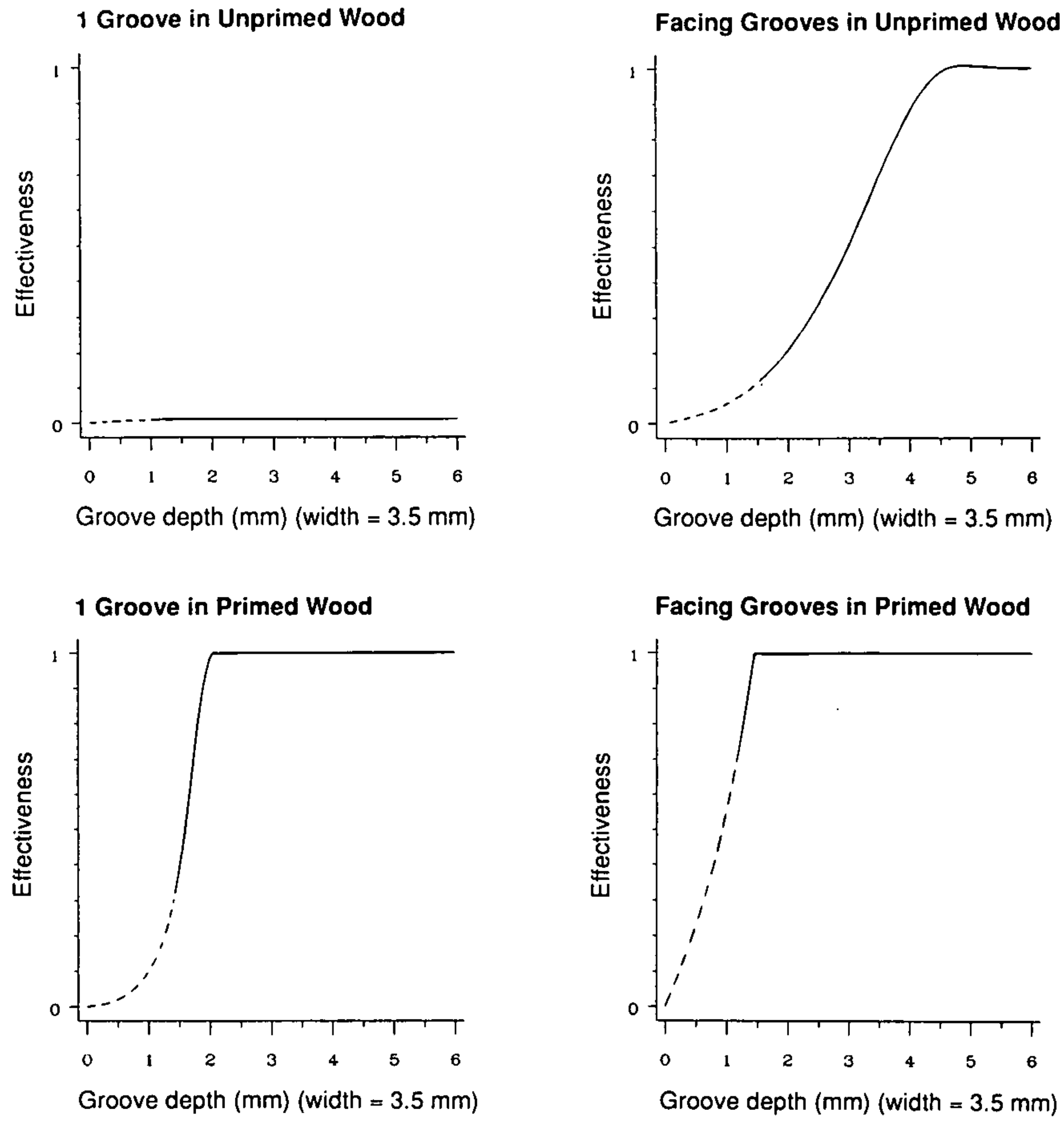

Fig. 6. Graphs of critical sizing of weathergrooves. Data taken with height of groove above free liquid surface $h = 30$ mm in unprimed wood, $h = 10$ mm in painted wood, (typical for weatherboards). Width of groove is nominally 3.5 mm (due to width of typical saw-blade) and joint is tight.

5.2. *Weathergrooves in primed wood under an applied pressure*

P_{tot} was set equal to zero at the lower groove edge by adjusting P_{app} to obtain an equilibrium position. Then the additional P_{app} required to breach the larger groove sizes (which had not been breached by capillary pressures alone) were measured. Figure 7 shows the effect on the hysteresis loop of rise versus pressure, of the presence of a weathergroove at $h = 45$ mm in height above the free liquid surface. It was found that the groove width y (for grooves between 2 and 7 mm wide and depth x, between 1.4 mm and 5 mm) had little effect on results when tested under the influence of an applied pressure, so experiments varying the depth of the weathergroove were primarily concentrated on. The breaching pressure that was measured in these experiments ranged from a minimum of 30 Pa for a very shallow groove, to a maximum pressure of 250 Pa, (for a wide and deep groove with a small joint width) which corresponds to wind speeds of around 25 to 70 km/hr (assuming a pressure coefficient C_p of 1) [11]. Table 2 shows the comparison between breaching

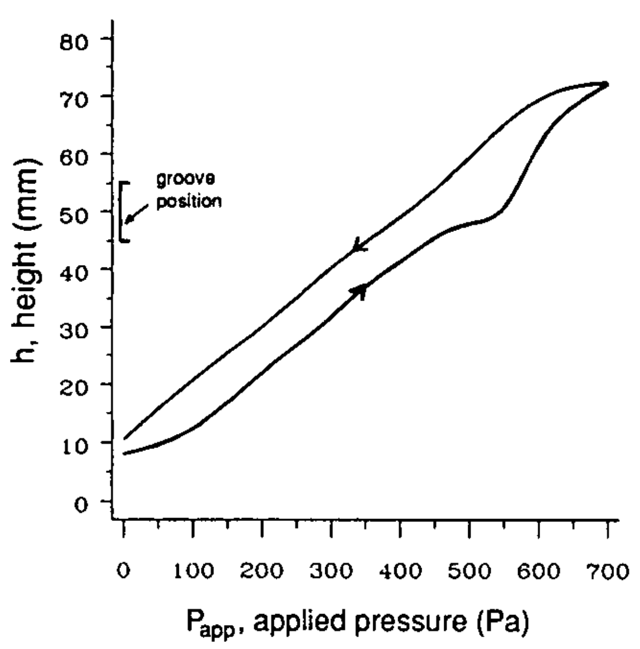

Fig. 7. Hysteresis plot of height vs applied pressure. Water driven into a simulated horizontal lap joint gap of 0.9 mm, to display the effect of a groove between $h = 45$ and 55 mm, in a pressure driven system.

Table 2. Comparison of predicted breaching pressures from theory, (assuming a contact angle of 70 degrees) and experimentally obtained breaching pressures. (Note that the contact angle and joint width are difficult to measure accurately, resulting in large errors occurring.)

Groove size (mm)	Joint width (mm)	Breaching pressure (Pa) from theory	Breaching pressure (Pa) from expt
1.8 × 3.5	1	90	90 ± 20
	0.5	150	150 ± 50
3.4 × 3.5	1	150	110 ± 40
	0.5	260	250 ± 50

pressures obtained experimentally, and those predicted by equation (4) for a single groove in primed timber, with a contact angle of 70 degrees. While the experimental measurements and the theoretical calculations agree within the experimental error, equation (4) is sensitive to changes in the value of θ and γ_l, both of which are temperature dependent. The values of d, and θ are also difficult to measure accurately. Errors of the same order as the predicted values can therefore occur in practice. So equation (4) can only be a useful guide to give the order of magnitude of a breaching pressure expected in a given situation, and as such the equation cannot readily be verified with these results.

Once breaching has occurred, and the applied pressure relieved, drainage of water from the joint was occasionally prevented by the weathergroove, as the resultant gravitational pressure available to empty the joint of water was not enough to overcome the surface tension forces at the groove.

5.3. *Weathergrooves in acrylic-plastic under an applied pressure*

This section was included to determine whether the slight porosity of a joint with primed surfaces, or Wenzel's roughness factor, $\mathscr{R}$, was influencing the results unduly. The contact angles for water on primed timber, and water on acrylic-plastic are similar, see Table 3, so comparison of results from this and the previous subsection is possible. Experimental results obtained for acrylic-plastic and wooden joints did agree as shown in Table 1, indicating that the porosity of a freshly primed surface and the roughness factor $\mathscr{R}$, had no measurable effect on results.

5.4. *Contact angle measurements*

Measurements of the contact angle of water on eight different wood primers, acrylic-plastic and fibre-cement boards, gave very different results to the angles formed on bare timber, or on weathered paint. See Table 3. This effect is partially due to the resultant decrease in porosity and roughness experienced if any priming coat is applied to an absorbent material, but also is due to the different pigments and vehicles used in different paints.

6. DISCUSSION

It has been demonstrated that weathergrooves are effective in preventing the upward rise of water through a joint by capillarity, especially if the contact angle is high e.g. in primed joints, and will also provide resistance to water ingress driven by wind pressure if large weathergrooves are used. Values of P_b have been calculated from equation (4) to give the breaching pressure of specific sized grooves in agreement with experiment, but limited accuracy in measuring and calculating these pressures restricts complete verification of the equation. If the surface finish can be modified to increase the contact angle of water at the solid surface, then this mechanism will prove a stronger retardant to capillary water rise than the existence of a weathergroove alone, but will not itself resist water penetration driven by pressure differences. In fact if a contact angle of >90 degrees can be maintained, then the upward pressure due to Γ is negative, and this causes a retraction of water from a joint, e.g. aluminium pigmented primer, or wax or silicone treated surfaces.

The weathering of a primed surface can cause an increase in the porosity of a surface [12], along with a possible decrease in contact angle, leading to deterioration in water retardant properties, but as the interior of a joint is protected from weathering, this effect is normally slight. Weathered paints and bare wood both displayed decreasing contact angles over a period of an hour, due to the finite porosity of these surfaces [13] and surface contamination.

While grooves in each side of an unprimed joint were shown in the short term to prevent capillary water rise, if a joint was to remain wet in windy conditions, for a period exceeding a few hours, then capillary rise in the fibres of the wood may eventually cause water to rise above the groove, and possibly lead to timber decay.

No attempt was made to simulate gusting wind in this work, as the system response time to an increase in pressure was too slow (between one and ten seconds) in comparison to the often higher frequency of wind gusts [15]. Wind pressures up to 250 Pa can be resisted by the weathergrooves tested here, as indicated in Table 2. This is a substantial performance, as seldom is more than half of any applied pressure dropped across any lined cladding [14]. If 80% of wind pressure can be dropped across an interior lining, and only 20% across the cladding, then this implies that wind-speeds of between 55 and 125 km/hr can be withstood before any water can penetrate through joints in the cladding containing weathergrooves. 125 km/hr is close to the design wind speed of a 3 second gust 10 m above the ground at a five

Table 3. Comparison of contact angles of water on various surfaces

Material	Surface finish	Contact angle (Degrees)
Plywood	Bare	30 ± 10
	Alkyd primer	86 ± 2
	Machine applied pink alkyd primer	70 ± 4
	Acrylic primer	80 ± 3
	Acrylic primer with aluminium pigment	100 ± 3
Weatherboard	Weathered paint	25 ± 10
	Weathered primer	75 ± 8
Acrylic-plastic	Bare	75 ± 3
Wood fibre-cement	Bare	70 ± 4
Sheet	Primed	75 ± 3

year return period, for a sheltered residential area in most of New Zealand [15]. In this case, weathergrooves will be very effective in preventing wind pressure driven water rise, as well as rise due solely to surface tension, i.e. capillarity.

7. CONCLUSIONS

- It has been demonstrated that weathergrooves can be effective, and the principle factors affecting their performance have been identified.
- Priming or painting a bare wooden surface will increase the contact angle, typically to 70 degrees, which halves the capillary rise possible for a given joint width.
- Surface treatments that increase the contact angle to 90 degrees or over, will prevent any capillary rise, and will actually cause 'capillary depression' i.e. force any water down, out of a joint. e.g. silicone or wax treatments. But the treatment has to be durable for life.
- Weathergrooves in porous materials such as unprimed wood, should be at least 3.5 mm wide and 4.0 mm deep and positioned on both sides of the joint at least 30 mm above anywhere that water can accumulate, to be effective against short term water penetration by capillarity.
- Weathergrooves in materials with primed surfaces should be at least 3.5 mm deep and 3.5 mm wide, and need only be on one face of the joint, to resist capillarity.
- Weathergrooves can be breached by sufficient wind pressure—typically between 30 and 250 Pa. This corresponds to a wind speed range of between 25 and 75 km/hr if all the wind pressure is dropped across the cladding, or a range of between 55 and 125 km/hr, if only 20% of wind pressure is dropped across the cladding.

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APPENDIX A

Derivation of Breaching Pressure

The force required for a volume of water to travel up through a weathergroove, is given by the sum of the forces required to create new interfaces of solid, liquid, and vapour, plus the force required to overcome the gravitational attraction of the mass of water involved. Breaching is defined as the intrusion of bulk water to fill the volume of the weathergroove to point 'D' in Fig. 3.4. Firstly the liquid-vapour interface must be extended to the larger width of the joint inside the groove. This creates new liquid-vapour, and solid-liquid interfaces, while destroying the solid-vapour interface, and gives the following:

$$F_1 = l(\gamma_{l\text{-}v} + \gamma_{l\text{-}s} - \gamma_{v\text{-}s}). \tag{A5}$$

Then the solid-vapour interfaces up the walls of the weathergroove must be replaced with solid-liquid interfaces giving:

$$F_2 = 2l(\gamma_{l\text{-}s} - \gamma_{v\text{-}s}). \tag{A6}$$

The wetting of the horizontal top of the weathergroove will reduce the total energy of this sytem as shown at point 'D' on Figure 3.4, so this component of energy is not included in the summation. The final contribution to the equation is from gravity:

$$F_3 = mg = \rho g y l(x+d) \tag{A7}$$

So the breaching pressure required to perform this quantity of work is given by the total force divided by the area of joint involved, to give the breaching pressure P_b:

$$P_b = \frac{(\gamma_{l\text{-}v} + \gamma_{l\text{-}s} - \gamma_{v\text{-}s}) + 2(\gamma_{l\text{-}s} - \gamma_{v\text{-}s}) + \rho g y(x+d)}{d} \tag{A8}$$

This may be simplified by use of Young's equation [5] to become

$$P_b = \frac{\gamma_{l\text{-}v} - 3\gamma_{l\text{-}v}\cos\theta + \rho g y(x+d)}{d}. \tag{A9}$$

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