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Dimensional instability of cement-bonded particleboard: The effect of surface coating

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Abstract

Cement-bonded particleboard (CBPB) as a composite of wood chips and reacted Portland cement is dimensionally unstable in service in the presence of changes in relative humidity (RH). One solution to this deficiency is the application of surface coatings to reduce its magnitude. The work reported here first evaluated the compatibility of various sealers to the highly alkaline surface of CBPB using small coupons of material. Three proprietary sealers were then applied to large-sized samples, and the most promising sealer was then subjected to long-term exposure. The test results indicated the following: (1) The ranking in effectiveness of sealers was proprietary system>model systems, and solvent-borne sealers>water-borne sealers. (2) The behaviour of coated CBPB reflected the change of RH, although the amplitude of the change was much reduced. CBPB coated with the most effective sealer showed 70–90% reduction in both mass and dimensions over the whole range of RH exposure, with the exception of the samples on moving from 65% to 90% RH compared with uncoated CBPB. (3) For the most effective sealer, doubling of the number of coats reduced mass change to about 60% that of a single coat during cyclic exposure and 20% to 70% for dimensions, but the level of reduction decreased as the number of coats increased. (4) All coatings showed a strong resistance to carbonation. Coated CBPB did not exhibit a consistent increase in mass and decrease in dimensions with cycles. (5) Under long-term exposure, there was a slight deterioration of the coatings. (6) The hysteresis loops for both mass and dimensional changes of coated CBPB moved upwards as the number of cycles increased; this is in contrast to that for dimensional change of uncoated CBPB.

Keywords: Surface coating; Adsorption; Carbonation; Stability, Deformation; Composite

1. Introduction

Cement-bonded particleboard (CBPB) has found widespread use as a wall lining in public buildings, external cladding, protective elements for fireproofing, specialised flooring, and sound insulation. In many of these applications, CBPB has shown itself to be an effective product, but in a few cases, problems have arisen due to its dimensional instability in the presence of changing relative humidity (RH). It is certainly not an inert material when compared with some all-mineral boards, although its performance in the presence of changing RH is certainly much better than that of other wood-based panels.

The dimensional movement proceeds through four major processes in CBPB [1–5]. The first is the inherent alkalinity of the cement paste which results in an aggressive environment for the chips embedded in it, resulting in their degradation. The second process is carbonation, with its consequential induction of stresses between the chips and cement paste during both wetting and drying. Carbonation of the cement paste reduces its volume due to the conversion of $Ca(OH)_2$ to $CaCO_3$, which crystallises out in the pores, thereby creating incompatible residual stresses between the chips and the cement paste, leading to significant volume shrinkage in time. The third process is the reaction of the movement of moisture into and out of the chips and the cement paste or the complete solid skeletal structure of the material. The fourth is the result of the internal stresses developed during the manufacture of CBPB.

There are three possible ways in which the dimensional movement of CBPB in the presence of changing RH could be reduced:

- by modification of the chips to reduce their hygroscopicity;

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- by modification of cement paste to reduce its permeability; and
- by the application of surface coatings to cut off the transportation path of moisture.

This paper evaluates the effectiveness of the application of surface coatings.

In the wood industry, coatings have for a long time been employed to provide protection against various physical agencies as well as conferring a decorative effect [6–9]. Such coatings can be classified as either water-borne coatings, which include water-soluble systems and emulsion systems [10], or solvent-borne coatings.

Attention has also been paid to the protection of concrete surfaces, especially for the prevention of carbonation of concrete [11–13]. However, compared with wood, concrete surfaces have a restricted list of candidate coating materials. Some primary coating properties that affect their compatibility with concrete surfaces include (1) tolerance to alkalinity; (2) moisture sensitivity; (3) cure shrinkage; (4) elasticity; (5) viscosity; and (6) permeability to moisture and CO_2 [14].

2. Selection of types of surface coatings for CBPB

The chemical and physical characteristics of CBPB preclude the use of certain coatings. Firstly, the CBPB surface is inherently highly alkaline which may adversely react with a variety of coatings. Secondly, the CBPB surface is comprised of numerous mini pores, which invariably contain some degree of moisture. This porosity can cause bubbling and pinholing of an applied coating due to the displacement of air or the expansion of trapped vapours. Thirdly, the CBPB surface exhibits relatively low tensile strength when compared to steel and solid wood surfaces, which may result in surface cracking and delamination of any coating. Fourthly, the CBPB experiences dimensional changes due to forces of expansion and contraction. Therefore, a suitable coating must be extensible when cured, resistant to high alkalinity, and resistant to water vapour and CO_2.

Four model and three proprietary sealers were selected for small-scale trials based on material availability, cost, and previous experience.

2.1. Model formulations

Four model systems were prepared in the laboratory, the composition of which is given in Table 1. The sealers were formulated from selected water-borne emulsion resins that potentially offered the required low moisture permeability and alkali resistance. For comparative purposes, all sealers were prepared at a solids content of 30% (by mass), using simple mixing procedures and the adjustment of the solids content with water. The rheology and stabilisation of the sealers were controlled by the use of hydroxy–propyl–methyl cellulose added at a constant 1.0% (by weight) to each of the formulations.

Table 1
Composition of the model sealers

Formulation	Polymer type	Emulsion resins (wt.%)	Cellulose thickener (wt.%)	Water (wt.%)
1	Polyvinylidene chloride copolymer, supplied at 55% solid content	53.5	1	45.5
2	Pure acrylic copolymer, supplied at 50% solid content	59	1	40
3	Styrene acrylic copolymer, supplied at 50% solid content	59	1	40
4	Vinyl chloride, polyvinylidene chloride, acrylic terpolymer, supplied at 58% solid content	51.5	1	47.5

Each sealer was prepared by slowly adding the cellulose thickener to the water using a high-speed stirrer. Stirring was continued until dissolution and thickening had occurred; this took about 30 min. The emulsion resin was then slowly added and stirred at low shear for a few minutes to ensure complete mixing. Each sealer was then stored in a glass container.

2.2. Proprietary sealers

Three proprietary sealers were obtained. These were

(1) a water-borne acrylic varnish of similar solid content to the model formulations; this was included as a control by which to judge the model formulations;
(2) a solvent-borne masonry sealer based on styrene butadiene resin having low water vapour transmission characteristics; and
(3) a CPB sealer—a solvent-borne sealer based on an undeclared resin system. This is the only commercial product specifically formulated for sealing CBPB. This product contained an inert filler material, presumably to moderate absorption of the applied coating by the substrate and to reduce moisture transmission by pore blocking.

3. Panel preparation

CBPB is a commercial product. It is a mixture of soft wood particles and Portland cement, together with some additives. Wood particles in the CBPB are approximately 10 to 35 mm in length and 0.2 to 0.35 mm in thickness. The CBPB consists of about 65% cement, 21% dry wood, 11% water, and 3% chemicals by weight.

CBPBs were cut up to produce the following three sets of test pieces, which were preconditioned at 20 °C/65% RH before testing:

(1) for small size laboratory tests, 100 × 100 × 12 mm;
(2) for large size tests, 600 × 600 × 12 mm; and
(3) for large size tests, 600 × 600 × 18 mm. The edges of these samples were coated with two coats of epoxy resin.

4. Methodology

4.1. Preliminary tests

The preliminary tests centred on the assessment of candidate sealers. Four sealers formulated in the laboratory and three proprietary sealers from industries were applied as single-coat treatment onto the small-sized CBPB (100 × 100 × 12 mm; see the previous section). These samples were then subjected to 90% RH. Mass change was monitored for about 3 years.

The results were expressed as the percentage of moisture uptake with time and were evaluated and compared to those of the control uncoated test pieces. These coatings with low efficacy were eliminated, while the remainders were selected for further investigation.

4.2. Main tests

As reported above, three sealers, namely, acrylic, styrene butadiene, and CPB sealer, were selected from the preliminary tests for further investigation. They were applied to large-sized samples of both 12- and 18-mm thicknesses. To assess the effects of film thickness, sealers were applied as one- and two-coat systems, and the most promising sealer (CPB sealer) was also applied as a three-coat system. All coated, together with the uncoated control CBPB, were then subjected to cyclic RH; the range was selected to embrace the extremes of RH likely to be encountered in service. Thus, the cycling regimes were

$$20\ ^\circ C/90\%\ RH \rightarrow 20\ ^\circ C/65\%\ RH \rightarrow 20\ ^\circ C/35\%\ RH$$

$$\uparrow \leftarrow 20\ ^\circ C/65\%\ RH \leftarrow \downarrow$$

After three cycles, only the uncoated control CBPB and the CBPB with two coats of CPB sealer (with the best performance) were continued to 10 cycles to examine its durability with time under cyclic RH.

Mass, thickness, and length of CBPBs were monitored at 24, 48, and 72 h, and then at 72-h intervals thereafter until constant dimensions had been reached. Dimensional changes were read to 0.001 mm using a dial gauge. The mass was measured to 0.01 g.

Three replicates were used in all tests.

5. Results and discussion

5.1. The assessment of candidate sealers

For comparative purposes, all sealers described previously were applied to the small-sized samples. The moisture uptake of the systems tested is shown in Table 2 and Fig. 1. The values given are the arithmetic means of the three replicate panels.

It appears that all the sealers tested reduced the moisture absorption of CBPB, although there were wide differences in performance. The water-borne formulations (whether model or proprietary systems) were, at best, only about half as effective as the solvent-borne sealers in reducing moisture uptake. After nearly 1000 days of exposure, panels coated with model formulations exhibited similar mass gains to the uncoated CBPB panels. The effectiveness of water-borne acrylic in proprietary system compared with the uncoated control panel reduced to about 24% over this period, while both solvent-borne systems retained a reduction of adsorption of about 45%. The high moisture uptake in water-borne systems is probably attributable to the much higher permeability [6] of water-borne coatings, and the effects of long-term wetting on both the coating and the CBPB (substrate) interface may bring about adhesion failure. More impermeable solvent-borne coatings produced a gradual moisture uptake during 90% RH exposure (Fig. 1).

The results of this test indicate that all the proprietary formulations are effective moisture barriers, with the solvent-borne coatings being the more effective. The model formulations resulted in poor performance (see Table 2) and were therefore eliminated from the large-sized sample tests.

5.2. Large-sized sample tests

Large-sized test pieces of CBPB were coated with three selected proprietary coatings and, together with the uncoated control samples, were subjected to cyclic RH regimes between 35% and 90% RH to represent severe service

Table 2
Mass change of small-sized coated CBPB expressed as a percentage of the control value of uncoated samples

Time (days)	7	15	30	60	295	965
Sealer type	Mass increase compared with that of control CBPB (%)					
Model formulations						
Polyvinylidene chloride	91	96	95	91	97	100
Acrylic	87	91	90	90	101	103
Styrene acrylic	73	75	69	65	74	95
Vinyl chloride	68	74	73	73	91	99
Proprietary formulations						
Acrylic	75	71	62	57	59	76
Styrene butadiene	20	28	35	42	46	58
CBPB sealer	23	29	37	43	44	51

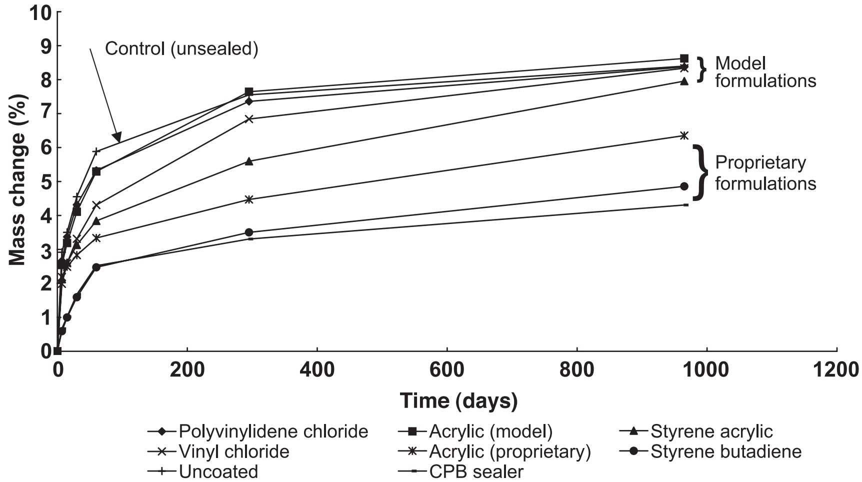

Fig. 1. Absorption of moisture vapour (mass %) with time by coated and uncoated small size CBPB in a climate of 20 °C/90% RH.

environments. The mass and length changes with time are shown in Fig. 2. The trend of thickness change is the same as that of length change.

The results confirmed those from the tests on small-sized samples; that is, the water-borne coating was less effective compared to solvent-borne coatings. Moreover, the degree of stabilisation of the substrate strongly depended on the level of the changing RH. Taking the first complete cycle as an example, the RH change from 65% to 90% resulted in only a small change in the length but had a strong influence on mass. During the cycle 90–65–35–65–90% RH, the ratio of mass change for the different stages of the cycle was 1.0:1.6:1.2:2.5 for acrylic coated boards compared to 1.0:1.3:1.3:2.5 for uncoated CBPB; the ratio of length change was 1.0:2.2:1.7:1.0 for acrylic coated boards compared to 1:2:2:1 for uncoated board. The similar relationship between movement and RH for both uncoated and acrylic sealer coated material indicates that the acrylic coating has a relatively high permeability.

The use of solvent-borne sealers were significantly more effective over the range of RH used in the test, with the exception of moving from 65% to 90% RH. This resulted in a consistent increase in both mass and dimensions. Thus, the CPB sealer resulted in a reduction of 70% in mass and 75% in length of test pieces subjected to a change in RH from 90% to 65%. The corresponding changes for styrene butadiene were about 40% in both mass and length. Greatest efficacy was associated with lower RH exposure. The ratio of the mass change of uncoated CBPB to CBPB with styrene butadiene to CBPB with CPB sealer was 3.4:2.2:1.0 on changing RH from 65% to 35%, and 12.0:3.1:1.0 from 35% to 65%; the corresponding ratios of length change were 4.1:1.7:1.0 and 7.7:2.4:1.0, respectively. For solvent-borne coatings, water penetration was restricted due to reduced permeability. CBPB coated with CPB sealer proved to be the most effective, probably a reflection of the inner added filler. The high increases in both mass and dimensional changes of coated CBPB under 90% RH

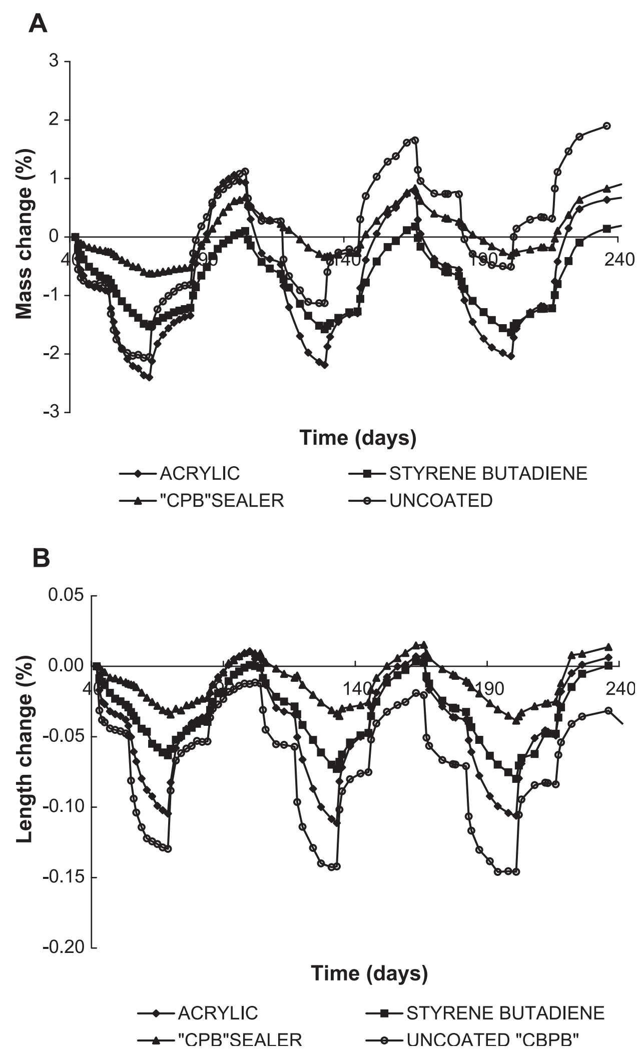

Fig. 2. Effect of various coatings on mass (A) and length (B) change of CBPB under cyclic RH.

exposure were possibly due to condensation of moisture on the surfaces or due to the penetration of water into the coatings where these did not withstand water. Therefore, it is generally desirable that the development of high moisture in service be prevented. It should be noted that the change in the thickness of coated CBPB was very similar to that in the length, although by different amounts.

5.3. The effect of film thickness on the movement of coated CBPB

Another group of boards was coated with two and three coats of the most effective sealer to investigate the effect of film thickness (Table 3). The changes are based on the values obtained after preconditioning at 90% RH.

It is apparent that an increase in the film thickness (i.e., number of coats) of water-borne acrylic did not produce reduced movement of substrate, but an increase in the film thickness of solvent-borne sealers had a pronounced effect. Table 3 shows that CBPB with one and two coats of acrylic sealer demonstrated very similar behaviour under cyclic RH, with the exception of the first desorption, where doubling of the number of coats increased the moisture loss to about 43% that of a single coat in moving from 90% to 65% RH. This again suggests an affinity of acrylic coating for moisture. A thicker film may hold more moisture and the moisture release when it was dried. However, after the first drying, the penetration proceeded further, and the formation of film was possibly improved.

By contrast, for the CPB sealer, an increase in film thickness resulted in a significant reduction in both adsorption and desorption over the whole range of cyclic RH. A doubling of the number of coats (taking the first cycle as example) reduced mass changes to about 56%, 51%, 60%, and 60%, respectively, of a single coat following the transfer of samples from 90% to 65% RH, 65% to 35% RH, 35% to 65% RH, and 65% to 90% RH. The corresponding length changes were 67%, 45%, 70%, and 45%, while the changes in thickness were 21%, 59%, 47%, and 34%. Further increases in film thickness did not bring about much efficacy in reducing the movement of the substrate—tripling of the number of coats only reduced the moisture change to about 25% to 30% of that of two coats resulting in 10% to 40% for length changes and 50% to 60% for thickness changes over the different RH ranges in the first cycle.

It is clearly in the interests of good performance of coated CBPB that a lower permeability of sealer is preferable considering the responses of coated boards to RH changes. However, adhesion retention and extensibility of the coating have not been taken into account. It has been observed that in general, low molecular weight sealers do not sufficiently prevent moisture movement and that sealers with high molecular weight ensure better substrate stability, although these may fail by flaking. Therefore, based on economic

Table 3
The effect of number of coats of sealer on the behaviour of CBPB (maximum change in %)

Sealer	Uncoated CBPB				Acrylic				CPB sealer							
Number	0				1 coat		2 coats		1 coat		2 coats		2 coats		3 coats	
Thickness of CBPB	12		18		12		12		12		12		18		18	
RH (%)	Mean	COV	Mean	COV	Mean	COV	Mean	COV	Mean	COV	Mean	COV	Mean	COV	Mean	COV
Mass change																
90–65	−0.78	8.89	−1.42	8.00	−0.93	5.21	−1.33	5.66	−0.25	5.66	−0.11	5.32	−0.14	8.32	−0.10	5.66
65–35	−1.27	6.24	−1.68	11.00	−1.47	4.36	−1.56	6.99	−0.37	9.69	−0.18	9.63	−0.40	9.66	−0.30	9.66
35–65	1.23	7.41	1.14	6.96	1.05	5.26	1.02	9.32	0.10	9.99	0.04	9.99	0.03	5.32	0.01	9.66
65–90	1.94	4.07	1.87	8.99	2.28	6.22	2.32	8.41	1.20	9.32	0.48	9.89	0.24	9.33	0.17	6.23
90–65	−0.85	3.44	−0.91	3.65	−1.40	9.88	−1.44	7.32	−0.45	6.32	−0.09	9.21	−0.07	6.32	−0.04	6.32
65–35	−1.40	3.33	−1.46	2.69	−1.72	8.33	−1.72	9.36	−0.57	5.26	−0.23	11.30	−0.35	2.00	−0.31	8.25
Length change																
90–65	−0.05	2.83	−0.07	6.36	−0.04	9.32	−0.04	11.30	−0.01	2.65	0.00	11.30	−0.01	9.22	−0.01	5.88
65–35	−0.08	10.49	−0.11	8.23	−0.06	15.60	−0.07	23.30	−0.02	9.66	−0.01	9.66	−0.03	6.12	−0.02	6.33
35–65	0.08	12.48	0.08	7.33	0.07	11.30	0.07	2.96	0.01	6.36	0.00	8.96	0.00	1.23	0.00	9.22
65–90	0.04	3.28	0.06	6.99	0.04	9.33	0.04	11.30	0.03	9.62	0.02	8.32	0.02	9.66	0.01	9.12
90–65	−0.04	11.88	−0.05	10.33	−0.04	9.23	−0.04	10.30	−0.02	6.35	0.00	7.23	−0.01	6.55	0.00	8.12
65–35	−0.08	9.89	−0.10	5.66	−0.08	9.12	−0.07	2.66	−0.03	8.56	−0.01	9.21	−0.03	6.78	−0.02	14.60
Thickness change																
90–65	−0.15	7.42	−0.23	11.20	−0.07	1.99	−0.08	9.66	−0.04	5.66	−0.03	14.20	−0.03	12.30	−0.01	12.30
65–35	−0.16	8.66	−0.26	10.30	−0.12	6.32	−0.16	8.98	−0.04	9.33	−0.02	5.69	−0.07	5.96	−0.03	9.99
35–65	0.14	3.36	0.18	8.63	0.10	8.23	0.11	7.35	0.02	8.32	0.01	6.98	0.00	9.63	0.00	8.00
65–90	0.12	13.62	0.17	9.33	0.12	8.11	0.14	9.00	0.05	9.12	0.03	9.32	0.02	8.65	0.01	6.23
90–65	−0.11	6.25	−0.12	9.63	−0.10	2.11	−0.12	5.60	−0.03	8.12	0.00	8.21	−0.01	8.96	−0.01	7.23
65–35	−0.16	10.36	−0.27	7.23	−0.14	11.30	−0.13	2.48	−0.03	8.66	−0.02	7.32	−0.07	9.36	−0.06	8.22

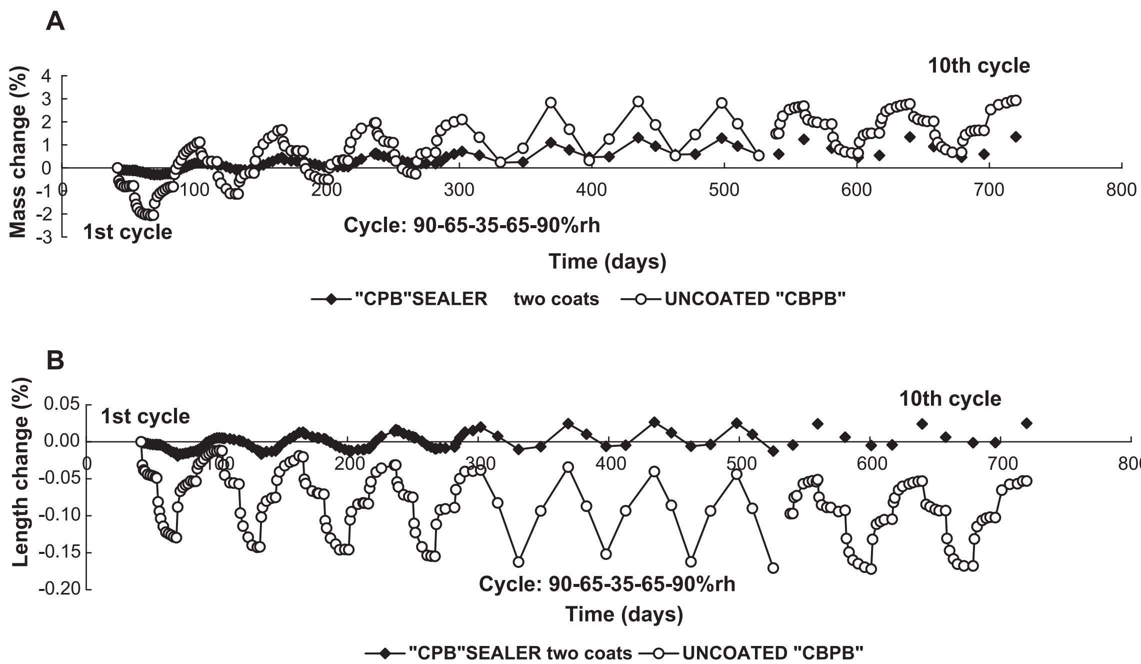

Fig. 3. Effect of cyclic RH (10 cycles) on mass (A) and length (B) change of CBPB with and without coating.

aspects and effectiveness, two coats are recommended as only slight movement of CBPB was found experimentally between two and three coats (see Fig. 3). Too thick a film may also cause cracking and displacement of the coating from the substrate if the film does not provide sufficient flexibility and adhesive properties.

5.4. The effect of board thickness

The ratio of the change for 18- and 12-mm CBPBs under various stages of RH is calculated and provided in Table 4. A *t* test was carried out to detect if the difference in change between different thickness of boards was significant.

From Table 4, it appears that for uncoated CBPB, the changes in both mass and dimensions of 18-mm boards were generally higher than those of 12-mm boards under various stages of cyclic exposure. The difference may be attributable to the difference in the percentage distribution of cement paste and wood chips across the thickness, or internal stress due to the moisture gradient, although the parameters of production of CBPB cannot be excluded.

For the CBPB coated with water-borne sealer (acrylic), the change in the mass of 18-mm boards was lower than that of 12-mm boards, with the exception of the change under desorption in the first cycle. However, the change in dimensions of 18-mm boards was higher than that of 12-mm CBPBs. The change in dimension of CBPB coated with solvent-borne sealer (CPB sealer), however, was contrary to the above. This result may be related to the great efficacy of the sealer which brought about very little change in both mass and dimensions when subjected to changing RH.

A *t* test analysis showed that no significant effect of thickness of CBPB, whether uncoated or coated with water-borne or solvent-borne sealer, was apparent. This indicates that the behaviour of CBPB from different sources may be the same or very similar.

5.5. Tests of the durability of CPB sealer and its prediction

The final aspect of the study was to subject the selected coating sample to a series of cycles. The experiment contained both uncoated CBPB and CBPB with two coats

Table 4
The ratio of percentage change of 12- and 18-mm CBPBs

RH (%)	Uncoated CBPB			Acrylic (2 coats)			CPB sealer (2 coats)		
	Mass	Length	Thickness	Mass	Length	Thickness	Mass	Length	Thickness
90–65	1.818	1.508	1.510	1.172	1.522	2.725	1.333	2.676	0.840
65–35	1.318	1.309	1.605	1.128	1.242	1.364	2.278	2.370	4.031
35–65	0.926	1.062	1.248	0.809	1.048	1.534	0.721	1.262	0.000
65–90	0.963	1.480	1.420	0.700	1.334	1.251	0.494	1.220	0.672
90–65	1.067	1.222	1.122	0.659	1.059	0.886	0.713	2.169	–
65–35	1.041	1.163	1.675	0.926	1.180	1.703	1.525	2.023	4.380

Table 5
The ratio of change in mass of uncoated/coated CBPB at various cycles

No. of cycles	65–90% RH	90–65% RH	65–35% RH	35–65% RH
1		7.2	7.2	3.4
2	4.7	1.9	13.1	2.1
3	3.6	2.6	16.2	5.8
4	3.2	2.5	1.6	3.6
5	2.9			2.5
9	2.2	2.2	1.4	2.8
10	2.1	2.2	1.5	2.7
11	2.2			

of CPB sealer to allow a direct comparison of the coating effectiveness and durability. The results of the test are presented in Table 5 and Figs. 3 and 4.

As the number of cycles increases, the behaviour of CBPB coated with CPB sealer changes due possibly to changes within the coating leading to loss of effectiveness. It appears that the level of change in mass of CBPB coated with CPB sealer increased (Table 5), while the length of CBPB increased rather than decreased as found for uncoated CBPB (Fig. 4). The deterioration of the sealers, causing an increase in both mass and dimensional change, is thought to be attributable to several mechanisms. Under RH exposure, the coating firstly swells causing a change in residual stresses of the coating and possibly microcrack formation. Secondly, the interface between CBPB and coating may be affected, which in turn would influence the durability. Thirdly, long-term exposure of coatings to wet conditions may lead to a deterioration in the mechanical properties as a result of hydrolysis and saponification.

It should be noted that the thickness change exactly followed that of length, although with a different amount of change.

It should also be noted that durability of coating systems depends not only on the coating itself but also on the substrate to which it is applied and the environment to which it is exposed, including light, moisture, temperature, and even trace elements. The results above should therefore be taken as only a general guide to performance in practice.

5.6. Sorption and dimensional change isotherms (hysteresis loops)

The combined adsorption and desorption parts of a cycle of RH gave rise to a hysteresis loop. An example of this is illustrated in Fig. 4. It should be noted that in each complete cycle, the higher curve of each pair forming the loop was obtained by exposing the CBPB (with two coats CPB sealer) to successively lower RHs and permitting sufficient time to reach equilibrium (i.e., dimensions were constant at each level of RH). The lower curve was the adsorption line obtained when the sample regained moisture at the same RHs to which it was exposed during desorption. There was a consistently vertical movement of the loops in successive cycles, with the first loop at the bottom for both mass and dimensions. This is in contrast to that of uncoated CBPB in which the top loop is the first one (for dimensions). The details of this were presented in a previous publication of this series of papers [4]. A similar shape of loop was found for both length and thickness.

These results indicate that the sorption–dimensional change relationship for coated CBPB was considerably

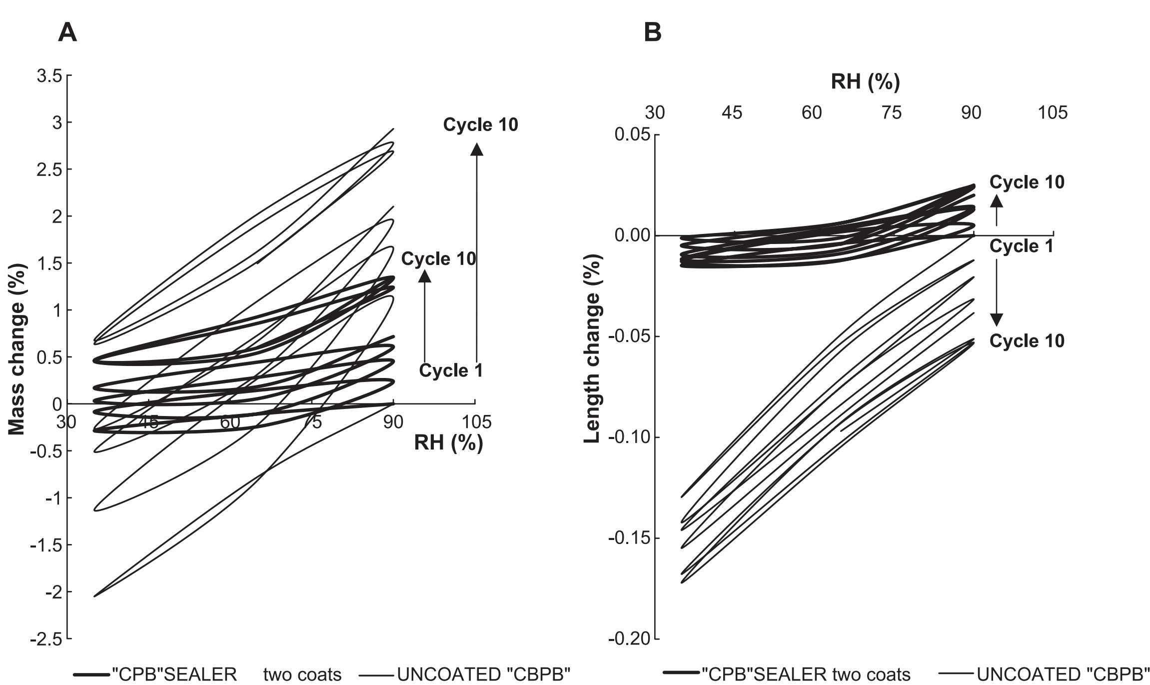

Fig. 4. Mass (A) and length (B) change under adsorption and desorption of CBPB with and without two coats of CPB sealer in 10 cyclic RH cycles.

different to that of uncoated CBPB. The movement of coated CBPB followed that of mass; that is, both mass and dimensions increased with cycle number.

Similar behaviour also occurred in the response of mass and dimensions to RH ranges. Only very slight increases were found when samples were moved from 35% to 65% RH, but a considerable increase was observed on moving samples from 65% to 90% RH. Mass and dimensional decreases were consistent over the whole range of desorption exposure, whether from 90% to 65% RH or from 65% to 35% RH. A much wider loop of length change was produced for the CBPB with two coats of CPB sealer due to the discontinuity in adsorption compared to that of uncoated CBPB. This sealer with its lower permeability is resistant to moisture penetration, resulting in a lesser degree of sorption in CBPB, which in turn proves to be more stable under adsorption. However, the prevention of sorption is not absolute; as long as the water is absorbed into the CBPB, the more resistant the sealer is, the more difficult moisture evaporation under desorption becomes.

The vertical movement of the loop clearly indicates an appreciable increase in mass with each successive cycle. From the first to the fifth and from the first to the tenth exposure to 90% RH, the mass increased by 0.7% and 1.3%, respectively, and 0.020% and 0.025% for length. These results again imply that the CPB sealer deteriorated with time (or cycle) and is more sensitive to high than to low RH.

5.7. The resistance to carbon dioxide of coated CBPB

The results above show not only the effectiveness of the coatings in reducing the instability of CBPB but also the potential resistance of coatings to carbon dioxide penetration as well. The resistance to carbonation of surface coatings applied to concrete has been investigated by several authors [12,15]. The mechanism of a coating applied over the exterior surface to reduce the rate of carbonation is that the coating acts as a barrier to the penetration of carbon dioxide, consequentially preventing or reducing the contact of $Ca(OH)_2$ with CO_2. In fact, it also prevents the ingress of liquid water. The resistance to carbonation of every system tested is illustrated in Fig. 2. Due to the nature of carbonation, the mass of uncoated CBPB increased consistently with increasing number of cycles (Fig. 2A), and the dimensions decreased (Fig. 2B) [3,4]. However, these trends were considerably reduced for coated CBPB and even disappeared in some cases.

A wide range in the resistance to CO_2 occurred between the coating systems due possibly to different physical and chemical changes on film formation. It is of interest that the water-borne acrylic did not produce significant dimensional stabilisation but did show a considerable resistance to CO_2. As cycle number increased, the absolute values of both mass and dimensional changes of CBPB coated with acrylic decreased. Cycling did not affect the behaviour of the CBPB coated with both solvent-borne sealers. The slight increase in mass of CBPB with CPB sealer is not thought to be due to carbonation (by virtue of the same trend in length) but is probably due to the deterioration of the coating. This can be confirmed by its behaviour on moving from 35% to 65% RH, in which only a very slight increase was observed in both mass and dimensions of CBPB coated with CPB sealer compared to the significant increase for uncoated CBPB.

A correlation between coating thickness and resistance to carbonation seemed not to be reflected in the results obtained (Table 3), although permeability clearly decreased with greater coating thickness. It is thought that the movement due to moisture change may overshadow the slight difference in movement due to carbonation between a single coat and multiple coats.

It seems that a similar effectiveness in resistance to carbonation covered the whole range of RH. This has also been reported for concrete [15].

The benefit produced by the resistance of coatings to carbonation can be seen when considering long-term exposure (Fig. 3). There is a considerable increase in mass and decrease in dimensions after 10 cycles of uncoated CBPB; however, only slight increases were found in both mass and dimensional increases for coated boards. These results also indicate that CBPB with two coats of CPB sealer possessed a permanent resistance to carbonation. Deterioration of the coating with time might reduce the effectiveness of the actual surface layer, but the sealer which has been absorbed into the bulk of the CBPB continued to remain effective with time.

5.8. Visual inspection

One of the essential characteristics of a coating performance is retention of appearance. The results in this work show no flaking or embrittlement occurred with the sealers tested, but an uneven patchiness in colour changes was readily seen. Overall, the coatings tested maintained an acceptable appearance after three cycles. Colour retention of water-borne acrylic is superior to that of both solvent-borne coatings which showed a tendency to yellowing. When CBPB with CPB sealer were kept at 90% RH, algal growth appeared on the top face of the panel due to the condensation of the water vapour giving the coating a dirty appearance. It has been reported [16,17] that algal growth is an important paint deterioration mechanism and can lead to, and even accelerate, further paint failure.

6. Conclusions

(1) Due to the high alkalinity of its surface, there is a restricted number of sealers applicable to CBPB. Among the sealers tested, the ranking order of their effectiveness was proprietary systems>model systems, and solvent-borne sealers>water-borne sealers. Of all the sealers tested, the CPB sealer was the most effective.

(2) The behaviour of coated CBPB reflected the changes in cyclic RH. CBPB with solvent-borne CPB sealer was less effective on moving the panels from 65% to 90% RH, producing a gradual moisture uptake. However, a change of RH from 90% to 65% brought about a 70–75% reduction in both mass and length compared with uncoated control test pieces; a change of RH from 65% to 35% and from 35% to 65% RH resulted in a reduction of 70–80% and 87–92%, respectively. The values of the change of CBPB coated with water-borne acrylic sealer were close to those of uncoated CBPB, but the trends in the changes were different. Obviously, it is desirable to avoid a high-RH environment in service.

(3) The efficacy of the solvent-borne coating significantly increased with film thickness (number of coatings), but this increased only slightly for the acrylic coating. A doubling of the number of coats reduced mass change to about 60% of that of a single coat during cyclic RH exposure, length change to about 45–70%, and thickness change to about 20–60% over the same RH frame, depending on both the level and range of RH. However, the level of reductions was reduced as the number of coats increased.

(4) The change in both mass and dimensions of uncoated CBPB under cyclic RH for 18-mm CBPB was higher than that for 12-mm CBPB. However, this did not appear to be the case if CBPB was coated with effective sealers. A t test showed no significance in changes in both mass and dimensions between 18- and 12-mm CBPBs, indicating that the behaviour of various kinds of commercial CBPB may be the same or very similar.

(5) There was a consistent deterioration of CBPB with CPB sealer subjected to either multiple cycles or long-term exposure. Both mass and dimensional changes increased as the number of cycles increased, instead of decreasing in length as for uncoated CBPB.

(6) The rate of changes of coated CBPB was different between adsorption and desorption (especially at high RH), giving rise to hysteresis loops. The loops for CBPB coated with CPB sealer were much flatter than those for uncoated CBPB, indicating a resistance to both moisture adsorption and desorption. Moreover, the loops for both mass and dimensional changes moved upwards, the reverse of that for dimensional changes of uncoated CBPB, showing the deterioration of coated CBPB with increasing cycle number.

(7) CBPB coated with all sealers showed a strong resistance to carbonation. Unlike the behaviour of uncoated CBPB, a consistent increase in mass and decrease in dimensions with increasing number of cycles or time were not observed. Although a water-borne acrylic sealer was not very effective in reducing either mass or dimensional change under changing RH, the efficacy of preventing carbonation was very significant. The resistance of coatings to carbonation was clearly not affected by multiple cycling under changing RH. This has significant benefit for the long-term performance of CBPB.

(8) The coatings maintained an acceptable appearance after a series of cycles, although there was a tendency of yellowing after prolonged periods of time.

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