

DIMENSIONAL STABILISATION OF CEMENT BONDED PARTICLEBOARD

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ABSTRACT

Cement bonded particleboard (CBPB) as a composite of wood chips and reacted Portland cement is unstable in service. The behaviour of CBPB is attributable to that of its components, and the structure and internal stresses of CBPB. As part of an extensive programme of research aimed at establishing methods of improving the stability of CBPB, this paper discusses the treatment processes for stabilisation of CBPB. Three treatment processes, namely, steam treatment of wood chips, pre-drying of and application of surface coating on CBPB, were investigated. The results indicated that all three treatments were able to stabilise CBPB: 1) the efficacy of the stabilisation of CBPB was closely related to the duration of the steam treatment, with the dimensional changes for 5 minute treatment being about 1/3 that of untreated CBPB. 2) Pre-drying process resulted in an alteration of structure of CBPB and stabilised CBPB permanently. A considerably irreversible mass decrease and dimensional shrinkage occurred when re-wetting at 65%RH, being about 0.7% and 3% for mass, 0.02% and 0.12% for length, and 0.08% and 0.19% for thickness respectively for 35%RH and 105°C pre-drying CBPB. 3) Surface coating had a significant influence on the behaviour of CBPB due to physical and chemical reaction. CBPB coated with the most effective sealer showed 70-90% reduction in both mass and dimensions compared with uncoated CBPB.

KEYWORDS

Cement bonded particleboard; stability; steam treatment; drying; coating.

INTRODUCTION

There are various applications of cement bonded particleboard (CBPB) in construction which expose the material to a range of different environments (Dinwoodie and Paxton, 1988; Kuroki *et al.* 1994). Short term and long term durability studies have provided much information regarding its strength and related properties under various conditions (Dinwoodie and Paxton, 1990; Moslemi *et al.* 1994). However, CBPB, made of hygroscopic porous cement paste and wood chips, inevitably exhibits the characteristic of mass and dimensional change under both constant and changing relative humidity (RH) (Fan, *et al.* 2000a; 2000b), and this has been found to be very critical in the performance of a building. The contributions to the behaviour of CBPB have been reported in the previous paper (Fan, *et al.* 2004a). The present paper sets out the treatment processes in order to stabilise CBPB.

It has been found that the behaviour of CBPB (Fan, *et al.* 2004a) is attributable to 1) the behaviour of its components-wood chips and cement paste; 2) the carbonation and carbonation-induced shrinkage of CBPB; 3) the structure of CBPB, in which the orientation of wood chips determines the different movement between the length, width and thickness of CBPB; 4) the internal stresses developed during processing of raw materials and manufacture of CBPB. Accordingly there are at least three possible ways in which the dimensional stability of CBPB in the presence of changing RH could be improved:

- by modification of the chips to reduce their hygroscopicity;
- by modification of cement paste to reduce its permeability;

- by minimisation of springback by limiting the development of internal stresses or relieving internal stresses within the pressed board or relaxing internal stresses during mat consolidation;
- by post-treatment for CBPB product.

This paper presents the treatment processes for both chips and CBPB product to stabilise CBPB. The treatment processes are 1) the steam pre-treatment process for producing stable CBPB and 2) pre-drying treatment of CBPB and 3) surface coating.

MATERIALS AND PROCEDURE

For pre-treatment of wood chips

Materials: Wood particles were obtained from a UK commercial manufacturer. A gyratory screen equipped with a 10 mesh screen was used to remove oversized particles. Fresh OPC, sodium silicate and aluminium sulphate were supplied by a commercial company.

Steam Pre-treatment: Wood particles were loaded into a steam treatment chamber. Saturated steam at a pressure of 1.5MPa was injected. After a predetermined time, i.e. 1, 2, 3, 4, 5 minutes, the steam pressure was released and the chamber opened for unloading of treated particles.

Board making: Board dimension: 500x500x18mm; Target board density: 1200kg/m³; Board construction: with the same procedure as that of commercial products. The detailed can be referred to the previous publication (Fan, 1997).

For pre-drying treatment and surface coating

Samples were removed from panels taken from the commercial production lines. All samples were exposed under normal environmental condition of 20°C/65% relative humidity (RH) for about 2 months before test. The details of samples used are set out in Table 1. Further information can be found in previous publication (Fan, 1997).

Mass, thickness and length of CBPB were monitored at 24 h, 48 h, 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. The results were expressed as a change of % initial values.

Table 1 Experimental materials and procedure

Treatment process	Materials: Dimension (mm)	Test condition	Replicate
Pre-drying CBPB	Edge sealed CBPB: 600x300x18 ¹⁾	Exposed at:	3
		20°C/65%RH;	3
		20°C/35%RH; oven dry (105°C) and then cyclic RH ²⁾	3
Application of surface coating ³⁾	Unsealed CBPB: 100 × 100 × 12	20°C/90%RH	3
	Edge sealed CBPB: 600 × 600 × 12 ¹⁾	Cyclic RH ²⁾	3

1) The edges of these samples were coated with 2 coats of epoxy resin.

2) The cyclic RH range was selected to embrace the extremes of RH likely to be encountered in service, that is, the cycling regimes were: -

$$20^{\circ}\text{C} / 90\% \text{RH} \text{-----} \rightarrow 20^{\circ}\text{C} / 65\% \text{RH} \text{-----} \rightarrow 20^{\circ}\text{C} / 35\% \text{RH}$$

$$\uparrow \text{-----} \leftarrow 20^{\circ}\text{C} / 65\% \text{RH} \leftarrow \text{-----} \downarrow$$

3) Based on the chemical and physical characteristics of CBPB, material availability, cost and previous experience, three proprietary sealers were selected for small scale trials, namely acrylic, styrene butadiene and CPB sealer, and then further applied to large size samples of 600x600x12 mm. 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.

Changes in the thickness and length of CBPB after 24 hours and 72 hours (steam pre-treated), and changes in mass and dimensions of CBPB subjected to various relative humidity regimes were recorded. The recorded changes were then converted into percentage values with respect to the originally conditioned values.

RESULTS AND DISCUSSION

Effect of steam pre-treatment time on CBPB

The properties of CBPB made with the wood particles pre-treated for various time periods, i.e. 0 (control, no steam treatment), 1, 2, 3, 4 and 5 minutes, have been summarized in Tables 2 and 3. The pressure of saturated steam was maintained at 1.5MPa. It is apparent that the thickness swelling of CBPB made with steam pre-treated particles was significantly lower than that of the control as measured after soaking periods of 24 and 72 hours (Table 2). CBPB made with the wood particles subjected to 5 minute steam pre-treatment have only about 1/3 thickness swelling compared to that of the untreated CBPB. There is a similar effect on the length change of CBPB after soaked in water 24 and 72 hours.

The linear expansion and thickness swelling of CBPB were also reduced when the test pieces were transferred from equilibrium at 30 % relative humidity to equilibrium at 90% relative humidity (Table 3). Both the linear expansion and thickness swelling gradually decreased with increasing pre-treatment times of 1 to 4 minutes and then levelled off for treatments of 4 to 5 minutes.

Table 2 Effect of steam pre-treatment time on thickness swelling and linear expansion after water soaking

Pre-treatment time (min)	Thickness swelling (%)		Linear expansion (%)	
	24h	72h	24h	72h
0	1.81	2.24	0.18	0.22
1	1.42	1.68	0.12	0.17
2	1.01	1.24	0.10	0.13
3	0.82	0.96	0.09	0.11
4	0.73	0.82	0.08	0.10
5	0.65	0.73	0.08	0.09

Table 3 Effect of steam pre-treatment time on thickness and length change with change in relative humidity from 30% to 90%

Pre-treatment time (min)	Thickness change (%)	Length change (%)
0	0.16	0.28
1	0.12	0.21
2	0.10	0.17
3	0.09	0.14
4	0.08	0.12
5	0.08	0.12

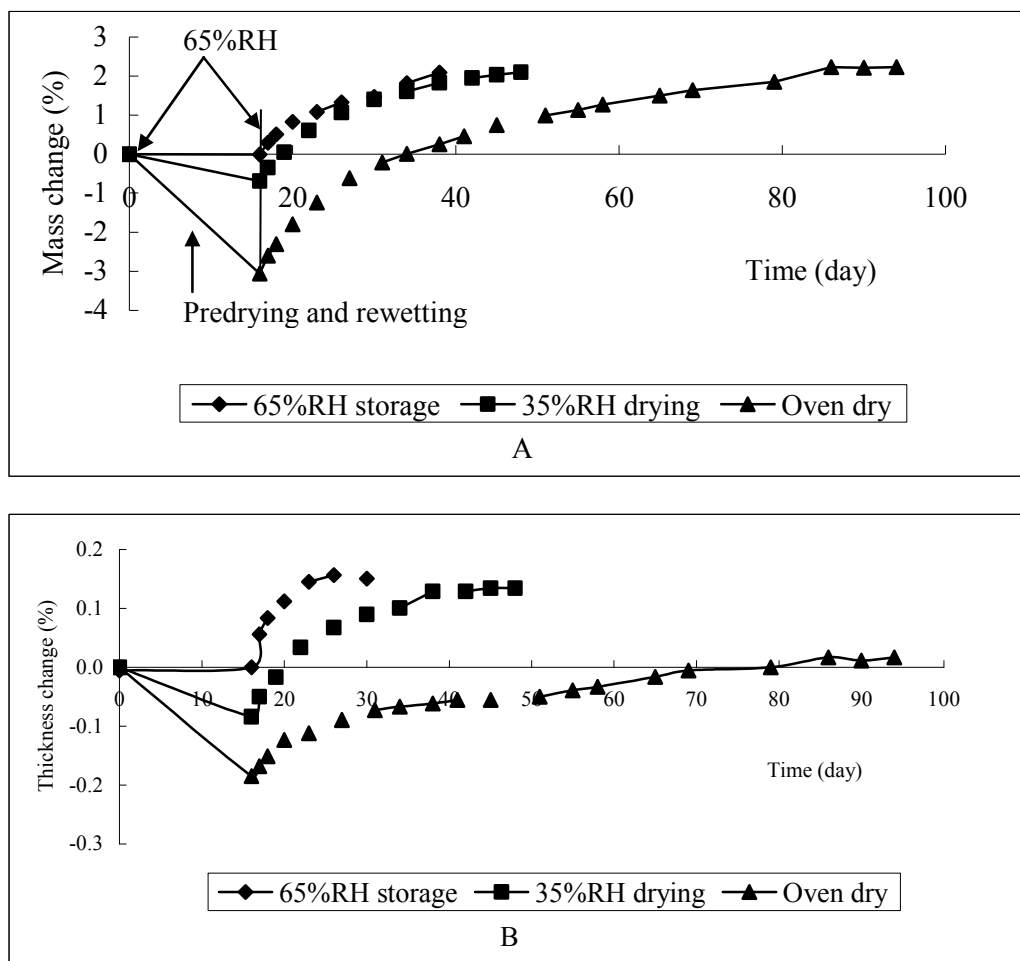
CBPB can be regarded as a composite of two materials (Fan, et al 2004b). The movement of CBPB are not only contributable to wood particles and cement paste (Fan et al 2006), but also the development of incompatible stresses within CBPB, especially residual stresses in wood chips. During fabrication, pressing and curing of CBPB, wood particles are contorted and compressed, in particular for CBPB products, a long period is required to cure the cement paste, inducing dimensional shrinkage of panels. Because the stiffness of cement paste is higher than that of wood particles, this extended curing could result in great stress on the wood particles. Steam pre-treatment may have increased the hydrophobicity of wood particles and resulted in a partial hydrolysis of wood particles. Consequently, both changes in wood particles themselves and internal stresses within the CBPB were reduced.

Effect of pre-drying on the behaviour of CBPB

Table 4 and Figure 1 summarise the mass and dimensional changes of CBPB subjected to re-wetting to the original condition (20°C/65%RH) and further high RH wetting (20°C/90%RH) after three different pre-drying regimes.

Table 4 Ultimate values of change of CBPB after re-wetting and further high RH wetting (%)

Schedule	Mass		Length		Thickness	
	65%RH	90%RH	65%RH	90%RH	65%RH	90%RH
65%RH exposure	0.01	2.09	0.00	0.06	-0.01	0.15
35%RH drying	-0.69	2.10	-0.02	0.03	-0.08	0.13
105C drying	-3.06	2.15	-0.11	-0.04	-0.19	0.02

**Figure 1** Mass (A) and thickness (B) change of pre-drying CBPB under 90%RH exposure

Mass change: CBPB dried under 35%RH or 105°C showed (Figure 1A) a considerable irreversible mass change after re-wetting, about 0.7 % mass decrease was recorded to be irrecoverable under 35%RH drying and about 3% with 105°C drying. However, the ultimate values of the mass increase after further high RH wetting were found to be independent of pre-drying, although they somewhat depend upon the time to reach the constant. After further high RH wetting, all samples reached a similar level of mass change, increased by about 2.1% and the end points of mass gain lay on almost a straight line.

Dimensional change: Unlike the behaviour for mass, CBPB shows very different behaviour regarding changes in dimensions depending on the drying schedules used. There existed considerable irreversible dimensional shrinkage after re-wetting. The degree of irreversibility strongly depended on the degree of drying. About 0.085% thickness shrinkage of CBPB with 35%RH drying remained irreversible and 0.185% remained with 105°C drying. Moreover, further high RH wetting resulted in different dimensional changes. After 90%RH exposure, the thickness of CBPB after 105°C pre-drying merely expand to its original value at 65%RH pre-conditioning, but with 65%RH prolonged exposure had 0.15% expansion and with 35%RH

drying produced 0.13% expansion. A similar situation was seen in length changes though with lower magnitude. However, the difference in ultimate changing values between three pre-dryings was reduced (Table 4). These results indicate that a stabilisation process occurs in CBPB during pre-drying. There existed a structural change for cement paste in CBPB during drying, and that the wood particles played a certain role in the dimensional change in terms of its isotropicity or their distribution within CBPB. A portion of the pores of the cement paste in CBPB may be enlarged, and unable to produce the capillary effect under low RH (65%).

Since both the mass and dimensions are irreversible under re-wetting, but further high RH wetting resulted in a compensation of the mass decrease, while the dimensions remained irreversible, it became very important to find out whether/why these changes were really irreversible, or the recovery was merely very slow. To answer this question, the final changing rate of CBPB was evaluated (Table 5). According to the cementitious work (eg. Helmuth and Turk, 1967), it was stated that cement paste may continue to expand throughout the re-wetting period, but the prolonged expansions of these wet specimens are not believed to be slow recovery following drying shrinkage. Re-wetting may be considered complete when the normal expansion rate for the paste during moist exposure is observed although the time required to re-wet depends upon the drying history. In terms of the changing rates of CBPB tested (Table 5), it was concluded that the procedure of drying or wetting was complete and there did exist permanently irreversible changes in both length and thickness, and whatever the drying histories are, the mass can recover to its original values under high RH wetting. In addition to the aforementioned reasons, this is partly attributable to 1) the irreversible behaviour of wood particles which has been described in terms of differences in contact angle of the advancing and receding water front within the cell cavities, or in terms of the behaviour of the hydroxyl groups, some of which in both the cellulose and lignin permanently satisfy each other on drying, and some of which have irreversible inelastic exchange between neighbouring cellulose molecules (Skaar, 1988); 2) the behaviour of cement paste: drying results in the closing of gaps between gel particles and between intercrystal layers of cement paste following expulsion of water confined between adjacent surfaces. The contraction of such small inter-solid gaps is accompanied by steep increase in Van der Waals binding forces and by the formation of new chemical or physical bonds. Raising the RH at the lower level would not result in full recovery of these gaps owing to the inability of water molecules to reoccupy the newly closed original spaces; 3) the change in the structure of CBPB: the heating treatment affects the structure of the paste and its composition. Generally speaking, heating results in a considerable reduction in shrinkage (Powers, *et al.* 1959). No pores of the size of gel pores in normally cured paste are present in paste treated in an autoclave, so during 65%RH exposure a number of larger pores in dried CBPB were not filled with water, and the mass change of corresponding dried CBPB did not recover to its original values; whilst at 90%RH exposure most of pores left were refilled with water, the mass of CBPB recovered and compensated the previous change. This also suggested that condensation play an important role in the mass change of CBPB under high RH which, inversely, had much less effect on dimensional change.

Table 5 Final rate of change of CBPB after re-wetting and further high RH wetting

Schedule	Mass		Length		Thickness	
	65%RH	90%RH	65%RH	90%RH	65%RH	90%RH
65%RH exposure	2.1×10^{-3}	4.3×10^{-3}	2.5×10^{-4}	2.5×10^{-4}	1.3×10^{-3}	1.3×10^{-3}
35%RH drying	2.8×10^{-3}	3.8×10^{-3}	2.5×10^{-4}	2.5×10^{-4}	1.3×10^{-3}	1.3×10^{-3}
105C drying	2.2×10^{-3}	4.2×10^{-3}	2.6×10^{-4}	2.6×10^{-4}	1.4×10^{-3}	1.3×10^{-3}

Effect of surface coating

Adsorption at 90% relative humidity: The efficacy of three sealers to reduce moisture uptake is shown in Table 6. It was found that there were wide differences in performance between sealers. The water-borne formulations were at best only about half as effective as the solvent-borne sealers in reducing moisture uptake. Nearly 1000 days exposure showed that 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 42 and 49% respectively.

Table 6 Moisture uptake of small size CBPB (expressed as a % of the value of uncoated CBPB) (%)

Time (day)	7	15	30	60	295	965
Acrylic	75	71	62	57	59	76
Styrene butadiene	20	28	35	42	46	58
CBPB Sealer	23	29	37	43	44	51

Sorption under cyclic humidity: The mass and dimensional changes with time of large size test pieces subjected to cyclic RH regimes between 35 and 90%RH are shown in Figure 2. 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. Among three sealers used, the CPB sealer is the most effective over the range of RH used, resulting in a reduction of 70-92% in mass and 75-83% in length of test pieces, depending on the level of the changing RH. The change in the thickness of coated CBPB was very similar to that in the length, though by different amounts.

A comparison of the change of coated and un-coated CBPB subjected to 10 cyclic RH cycles showed that the stabilisation of CBPB by surface coating was very durable under changing RH. There was no deduction of efficacy observable after 10 cycles (Figure 3).

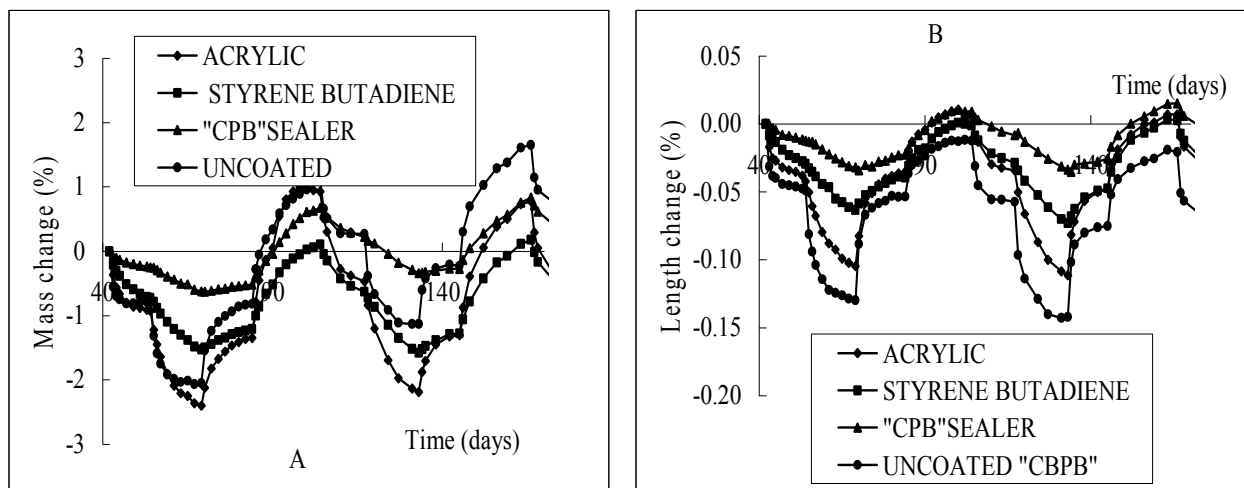


Figure 2 Effect of coatings on mass (A) and length (B) change of CBPB under cyclic RH

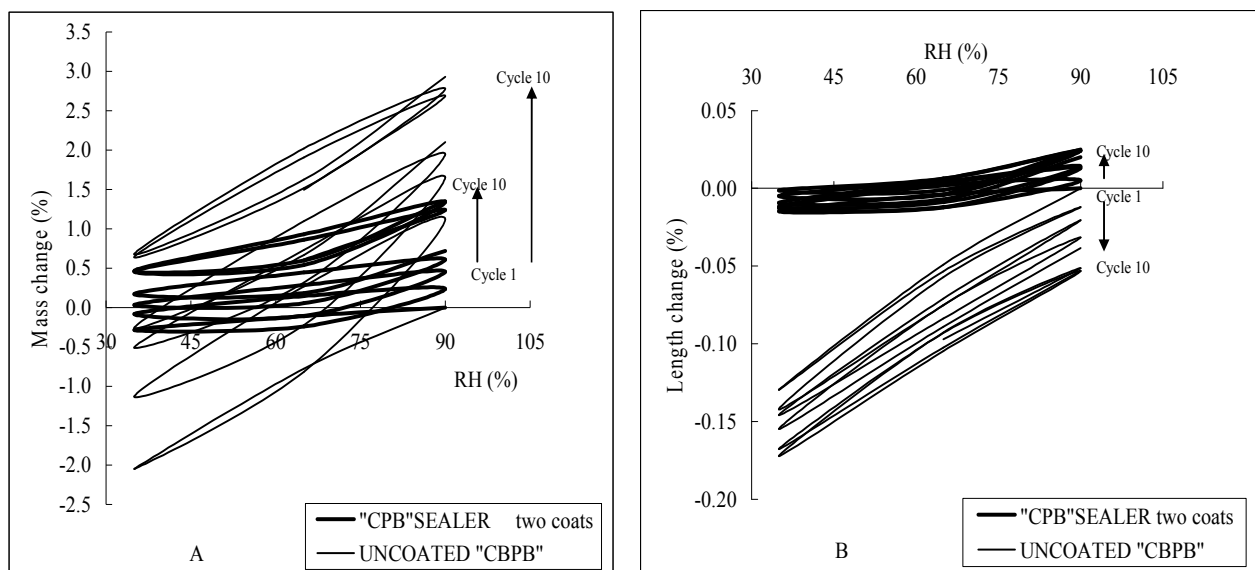


Figure 3 Mass (A) and length (B) change of uncoated and coated CBPB in 10 cyclic RH cycles

CONCLUSIONS

This study has concluded that all three stabilisation processes were very effective to reduce both mass and dimensional changes of CBPB. However, the efficacy of the treatments varied with the schedules of the treatments:

- 1) The steam pre-treatment process stabilised CBPB with a significant reduction in thickness swelling and linear expansion for a short treatment time (i.e. 1 minute). However, the effectiveness of stabilisation progressively increased at a reduced rate when the pre-treatment time increases from one to five minutes.
- 2) Pre-drying resulted in an alteration of structure and permanent stabilisation of CBPB. The reduction in mass and dimensional change at each stage of consecutive cyclic RH was closely related to the severe level of drying schedules. The mass change of CBPB, however, was independent of the three different pre-drying schedules after exposure at 90%RH.
- 3) Surface coating effectively stabilised CBPB: Of all the sealers tested, the CPB sealer was the most effective, with a reduction of 70-92% in mass change and 75-83% in length change over a range of changing RH.
- 4) Long term cyclic exposure showed that the stabilisation of CBPB by surface coating was very durable under changing RH. There was no deduction of efficacy observable after 10 cycles.

REFERENCES

- Dinwoodie, J. M. and Paxton, B. H. 1990. "The long term performance of cement bonded particleboard. In: Proc. 2nd Inter. Conf. on Inorganic bonded wood and fiber composite materials". Moslemi, A.A. (Ed). pp45-55.
- Dinwoodie, J. M. and Paxton, B. H. 1988. "A technical assessment of wood-cement particleboard. Proc. 1st inter. conf. on fiber and particleboards bonded with inorganic binder". Idaho, 115 - 125
- Fan, M. Z., Dinwoodie, J. M., Bonfield, P. W. and Breese, M. C. 2000a. "Dimensional instability of cement bonded particleboard: Part 1 Behaviour and modelling prediction under a constant and single change in RH". Wood Sci. Technol. (in press).

- Fan, M. Z., Dinwoodie, J. M., Bonfield, P. W. and Breese, M. C. (2000b) "Dimensional instability of cement bonded particleboard: Part 2 Behaviour and its prediction under cyclic changes in RH". Wood Sci. Technol. (in press).
- Fan, M. Z., Dinwoodie, J. M., Bonfield, P. W. and Breese, M. C. 2004b. "Dimensional instability of cement bonded particleboard: Contributions to its occurrence". Wood Sci. Technol. 38:335-347.
- Fan, M. Z., Dinwoodie, J. M., Bonfield, P. W. and Breese, M. C. 2004a. "Dimensional instability of cement bonded particleboard: Modelling CBPB as a composite of two materials". Wood Sci. Technol. 37:373-383.
- Fan, M. Z., Dinwoodie, J. M., Bonfield, P. W. and Breese, M. C. 2006. "Nature and behaviour of CBPB: Part 1 Structural, physical properties and movement. J of Materials Science. 41:5666-5678.
- Fan, M. Z. 1997. *Dimensional instability of cement bonded particleboard: Understanding its occurrence and reducing its magnitude*. PhD thesis. University of Wales.
- Helmuth, R. A. and Turk, D. 1967. "The reversible and irreversible drying shrinkage of hardened Portland cement and tricalcium silicate paste". J. of the PCA Research Development Laboratories, May.
- Kuroki, Y. 1994. "Manufacture of light weight cement bonded particleboard in Japan. Proc. 4nd inter. conf. on fiber and particleboards bonded with inorganic binder". Spokane, 105 -112
- Moslemi, A. A. 1994. "Accelerated ageing of cement bonded particleboard. Proc. 4nd inter. conf. on fiber and particleboards bonded with inorganic binder". Spokane, 83 - 88
- Powers, T. C. and Brownyard, T.L. 1959. "Capillary continuing or discontinuing in cement paste". J. of the PCA Research Development Laboratories, May.
- Reardon, E.J and Abouchar, M. 1989. "High pressure carbonation of cementitious grouts". Cement and Concrete Research. 19:835-839.
- Skaar, C. 1988. *Wood-water relations*. Springer Verlag Berlin.