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Dimensional instability of cement-bonded particleboard
Mechanisms of deformation of CBPB

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Abstract

Mechanisms of deformation of cement-bonded particleboard (CBPB) are discussed. The results, generated from subjecting CBPB to changing relative humidity in normal air and air devoid of CO_2, confirm that the mass and dimensional changes of CBPB are attributable to the combined effects of moisture reaction, carbonation of the cement paste, and degradation of the wood chips, all of which generate incompatible stresses. Moisture movement contributed to the deformation to a large extent. This deformation in CBPB arising from drying and wetting comprised at least five distinct stages and showed an association with both the types of water and the features of wood chips and cement paste. The carbonation mechanism of CBPB becomes operative and significant with longer periods of exposure, and the degree of carbonation is strongly related to the level of relative humidity. The generation and distribution of stress has a significant influence on the dimensional changes of CBPB, with the change in thickness being much higher than that in length.

Keywords: Humidity; Adsorption; Carbonation; Stability (deformation); Composite

There are various applications of cement-bonded particleboard (CBPB) in construction. CBPB is a composite of hygroscopic porous cement paste and wood chips. Previous papers in this series have shown that CBPB adsorbs moisture when relative humidity (RH) increases and desorbs moisture when RH decreases, causing corresponding swelling and shrinkage [1–2]. The marked increase in mass and shrinkage in dimensions have been illustrated when CBPB was exposed to various air conditions [1–3]. This change is due in part to the normal instability of wood and cement paste to water, and in part to the effects of carbonation, high alkali, and the generation of incompatible stresses. Thus, the drying shrinkage of cement paste may involve an isotropic dimensional change up to 5% [4], while the shrinkage of wood normally ranges from 0.1 to 10%, depending on species and orientation (longitudinal shrinkage is less than 10% that of the transverse, while the transverse radial shrinkage is about 60–70% that of the corresponding tangential figure [5]).

Part of the changes in dimension in CBPB reported on previously [1,2,6] was ascribed to carbonation; carbonation-induced shrinkage of portland cement products has been of special interest in the cementitous area for a long time [7–9]. Lightweight concretes are very susceptible to carbonation and carbonation effects because of their usually higher permeability. The problem of shrinkage is further aggravated by the higher compressibility of the aggregate.

CBPB may be regarded as a two-phase composite material in which the discontinuous phase is the wood chips and the matrix phase is the hardened cement paste. All factors that affect the deformation of both wood chips and cement paste also affect the deformation of CBPB, and these have been discussed in a series of separate papers. This part of the project was designed and conducted to examine the structure and nature of CBPB, and consequently to understand the mechanisms of sorption and deformation of CBPB. Part of the results of a large and comprehensive investigation into behaviour of CBPB was set out to examine the validity of the deformation mechanism theories.

1. Deformation mechanisms of CBPB

1.1. Structure of CBPB

The structures of cement paste and wood chips under the microscope are very complex. For the cement paste, both microcrystalline and colloidal materials appear; the colloidal material occurs as an amorphous mass enclosing microcrystalline [$Ca(OH)_2$] and unhydrated residuals of the original cement grains. Pores in the cement paste include both

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gel pores and capillary pores. For wood chips, the structure is comprised of cells that, for softwood, consists of both tracheids and parenchyma. Overall 90–95% of cells are aligned in the vertical axis (the tracheids), while the remaining percentage (the parenchyma) is present in transverse radial bands. The cells are hollow and the lumens (cell cavities) are interconnected by pores (pits) of different kinds.

The interface between the cement paste and the wood chips of CBPB consists of a transition zone that does not develop the dense microstructure typical of the bulk matrix and contains a large volume of calcium hydroxide crystals deposited in large cavities. Scanning electron microscopy photomicrographs illustrated that: (1) Generally, there was very close contact between the cement paste and the surface of the lumens of those open or fractured cells where fracture has permitted easy access, or the actual surface of wood chips. Sufficient cement paste enters the fractured cell lumens before pressing. However, no evidence of any hydrated or unhydrated cement constituents penetrating nonfractured cell lumen within the wood substrate was found. (2) Those complete cells adjacent to the chip surface were generally deformed and nearly flattened. (3) Macromechanical bonding of cement paste and wood chips plays a significant role in the total bonding [10–12]. The sorption of CBPB therefore not only occurs separately in wood chips and cement paste, but is also complicated by the interfacial region. The deformation of the cells and voids of wood chips adjacent to the cement paste and the full or partial blocking or filling of the cell lumens or interconnecting pits with cement paste affects the transportation of moisture through the CBPB.

1.2. Water in CBPB

Water in the CBPB can be classified as follows:

“Free water,” which is present in CBPB in both the cement paste and the wood chips. It exists in the cell cavities or pores beyond the range of the surface forces of the solids in the CBPB. In wood, this water occurs above the fibre saturation point.

“Adsorbed/bound water,” which occurs in CBPB in both the cement paste and the wood chips. It has been proposed that this water is taken up on internal sorption sites attractive to water. In the cement paste it is confined between adjacent crystallite surfaces and adsorbed on the surface of the crystallites. In the case of wood, bound water is bonded (hydrogen bonding) to the matrix constituents that include hemicelluloses, lignin, and noncrystalline cellulose.

“Chemical water in cement paste,” which is chemically combined in hydrated cement compounds within CBPB and as such is part of the solid. This type of water in cement paste cannot be removed during normal drying.

It should be noted that at a certain RH, the amount of water adsorbed is very different between the two constituents due to marked differences in structure, though the mechanism of sorption is the same in both. Experimental results confirmed (see Table 1) that the cement paste under the same condition has a lower equilibrium moisture content (EMC) compared to the wood chips, and the differences in EMC of cement paste between the conditions (35, 65, or 90% RH) are much less than those of wood chips. The EMCs of CBPB lie between those of the cement paste and the wood chips.

1.3. Deformation mechanisms of CBPB with respect to moisture changes

The following is an attempt to explain the deformation mechanisms by means of a comprehensive hypothesis based on the features of cement paste and wood and referring to existing facts regarding the structure of CBPB. This explanation is based on cement paste with its more irregular structure and complemented with the wood chip, which is organised in a very regular pattern.

Physical deformation of CBPB can be attributable to at least four mechanisms and involves all types of evaporable water confined in the small spaces within the CBPB. It is apparent that these mechanisms will occur at different levels of RH.

1.3.1. Water immersion (complete saturation)

When CBPB is immersed in water for a long time, it can be regarded as saturated. All pores and cavities, whether in wood chips, cement paste, or their interface, are filled, though the duration required for saturation may depend on the structure of the interface and constituents, being much longer for cement paste than wood chips. The whole system is probably subject to a slow swelling process balanced by tension in the solid phase. It is believed that at the initial moment of exposure (prior to the start of any active shrinkage mechanism), the wet CBPB contracts slightly due to the relief of these tensile stresses.

1.3.2. RH 90 to 99.9%

At the commencement of desorption a fairly large mass loss is accompanied by only a small amount of shrinkage. Meniscus formation in channels and capillary cavities (the radius of pores ranging from 1 to 0.01 μm) subjects the whole system to elastic shrinkage due to an increase in the tensile forces of the water. In theory, the lumen in wood chips is too large (about 8–35 μm, for the Sitka spruce in the CBPB used) for this reaction. Some capillary pores in the cement paste (0.2–0.01 μm) and interfacial area play a major role in

Table 1
EMC of CBPB and its components tested at various RH regimes used (%)

Regime	CBPB	Cement paste	Wood chip
20°C/35% RH	4.24	3.83	8.53
20°C/65% RH	8.10	5.27	14.39
20°C/90% RH	12.68	7.40	19.59

determining the moisture content. However, in terms of complex shape of large cavities and deformation of wood cells and partial filling of the cement paste in the lumen of wood cells in the interfacial region, this function may exist in the tapering ends of cells and pits. The loss of this water plays little role in shrinkage since the forces involved are small.

1.3.3. RH 40 to 89.9%

Below 90% RH menisci can only exist in pores ranging from 0.01 to 0.002 μm as appear in the gel pores of cement paste (0.002–0.004 μm) and in the porous zone of the interface. Water in wood chips may only locate in the matrix constituents and the hydroxyl groups of the cellulose molecules in the noncrystalline regions. Further reduction in RH causes the formation of air bubbles in even smaller pores, with a corresponding increase in the tensile forces in the water and elastic contraction of the cement paste. The noncrystalline material in the cell wall of wood chips (varying from 8 to 33% RH) results in marked shrinkage due to the drying out of the water-reactive matrix (the microfibrils come into closer proximity with a commensurate increase in interfibrillar bonding and decrease in overall dimensions). However, it should be noted that at an RH approaching 40%, menisci disappear even in the cement paste, tending to relieve all elastic contraction due to tension in the pore water. This was obtained by Roper [13], who found that the loss of water from 40 to 20% RH was accompanied by almost no shrinkage of the cement paste.

1.3.4. RH 0 to 40%

With no pore water in the CBPB, strong tangential tensile forces arise in the adsorbed water/bound water attracted onto the crystal surfaces. Reductions in RH increase these forces with a rise in reactive compression in the solid. This process is probably slowed down below 10% RH, when only a little adsorbed water is present.

Within this range of RH, withdrawal of adsorbed water results in a spontaneous closing of the gaps occupied by the water adjacent to crystal surfaces and embedded between crystal layers. The high shrinkage rate is expected at the lower range (below 10% RH) due to the reduction in intracrystal layer spacing. Moreover, approaching 0% RH, drying shrinkage may be accompanied by some decomposition of hydrated products of cement paste due to liberation and expulsion of chemically bound hydroxylic water from within the crystal lattice.

In the reverse process, dry CBPB expands with increasing RH. It probably begins with water adsorbed onto crystal surfaces, relieving the tangential compression. Filling of all voids with pore water could only be effected by complete immersion.

However, during the expulsion of water between adjacent surfaces, the contraction of small intersolid substance occurs and is accompanied by the increase in the bonding forces or by the formation of new chemical or physical bonds. These processes are most intensive at lower RH levels. Raising the RH would not result in full recovery of these gaps, due to the inability of water molecules to reoccupy the newly closed original spaces, the differences in contact angle of the advancing and receding capillary water front within cavities, or the irreversible inelastic exchange of hydroxyl groups between neighbouring molecules.

It should be noted that prolonged immersion would induce tensile stresses in the intersolid bonds, disrupting some of the weak new links and permitting further recovery. But it is also possible that, at higher RHs, the adsorbed confined water may squeeze out slowly by prolonged hydrostatic compression, reducing the small intersolid gaps.

It should also be noted that the deformation of CBPB is not governed exclusively by the quantitative pattern of water loss or gain, but it also depends on the mode of stress imposed on the solids and the restraining effect of the structure as a whole. It is apparent that an irreversibility appears due to the mechanical stress induced in the interface by the difference in the deformation between the wood chip and cement paste, if the bonding strength between the cement paste and wood is strong enough to withstand the stress. Compression and tension stress on wood chip will lead to the smaller and larger dimensions respectively.

1.4. Deformation mechanisms with respect to carbonation of CBPB

The mechanism of carbonation of CBPB is likely to consist mainly of gaseous diffusion combined with chemical interaction. The chief chemical interaction is the reaction of CO_2 in the air (about 0.03% by volume) with $Ca(OH)_2$ liberated during cement hydration, with calcium silicate hydrate. This process results in decomposition of the hydration products of the cement paste in CBPB to form various minerals and water. Deformation of CBPB occurred. The representative functions are shown in Eq. (1):

$$CO_2 + Ca(OH)_2 \xrightarrow{\rightarrow H_2O} CaCO_3 + H_2O \tag{1}$$

and Eq. (2):

$$3CaO \cdot 2SiO_2 \cdot 3H_2O + 3CO_2 \rightarrow 3CaCO_3 + 2SiO_2 + 3H_2O \tag{2}$$

The feature of carbonation of CBPB can be summarised as:

1. Carbonation of CBPB can occur even at low CO_2 concentration and is closely related to the level of RH; maximum shrinkage occurs at about 50 to 75% RH.
2. Carbonation of CBPB is accompanied by a decrease in the amount of nonevaporable water in the cement paste, and consequently the density of CBPB increases significantly (Fig. 1).
3. Carbonation of CBPB has a marked effect on dimensions (shrinkage). Carbonation shrinkage is almost completely irreversible; it is a separate phenomenon

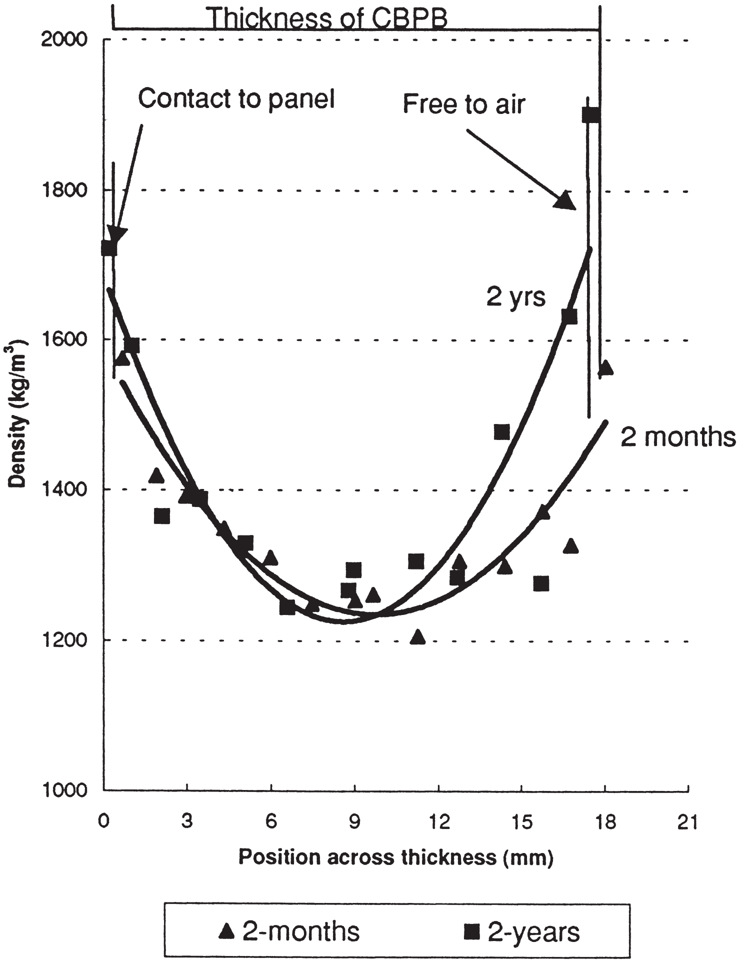

Fig. 1. Change in density profile of CBPB with different periods of carbonation.

to drying shrinkage and is superimposed upon the drying shrinkage. Carbonation proceeds inward from the exposed CBPB surface along a front roughly parallel to it. This was confirmed from the study of the density profile (Fig. 1).

In terms of the structure of CBPB, carbonation not only took place in the cement paste in the CBPB, but its presence may also be more significant in the interfacial region due to the less dense microstructure typical of the bulk matrix and the large volume of calcium hydroxide contained. The loose structure of wood chips in CBPB may provide pathways for carbon dioxide and enhance their reaction.

The dimensional change of CBPB resulting from carbonation is not due solely to the higher proportional change of cement paste due to carbonation; the change of CBPB may also be caused by a change in the wood chips due to the effect of stresses during the carbonation process. The shrinkage of cement paste due to carbonation is attributed to the dissolution of the calcium hydroxide crystal while the crystals are under pressure. Such dissolution temporarily increases stress in the remaining solids of the paste, bringing about a corresponding volume decrease [8]. This meanwhile exerts extra compression on the wood chips, thereby decreasing the volume of the wood chips.

1.5. Deformation mechanisms with respect to degradation of wood chips within CBPB

The wood chips within CBPB are surrounded by cement paste, which is highly alkaline in the presence of moisture. The calcium ions are deposited throughout the cell wall and not as a layer on the cell wall lumen surfaces [12]. The solution of a strong base is capable of removing a great part of the extractives and of dissolving considerable quantities of

Table 2
Exposure conditions of CBPB for the parallel experiments (20°C)

Aspect of work	Exposure condition*
Effect of CO_2 under constant RH	65% RH, normal air 65% RH, air devoid of CO_2
Effect of CO_2 under changing RH	35 → 90% RH, normal air 35 → 90% RH, air devoid of CO_2 90 → 35% RH, normal air 90 → 35% RH, air devoid of CO_2

* Normal air = indoor environmental air; air devoid of CO_2 = indoor environmental air with CO_2 trapped by carbosorb.

wood components, especially the hemicellulose, causing a loss of mass of materials and a change in dimensions. Consequently, the deformation of CBPB will be aggravated by the dimensional change of wood chips due to the alkali attack.

In addition to the incompatible stresses resulted from moisture reaction and carbonation of CBPB discussed above, the dissolution of soluble substances of the wood chips may increase stress in the remaining wood substances and surrounding solids of cement paste, resulting in a corre-

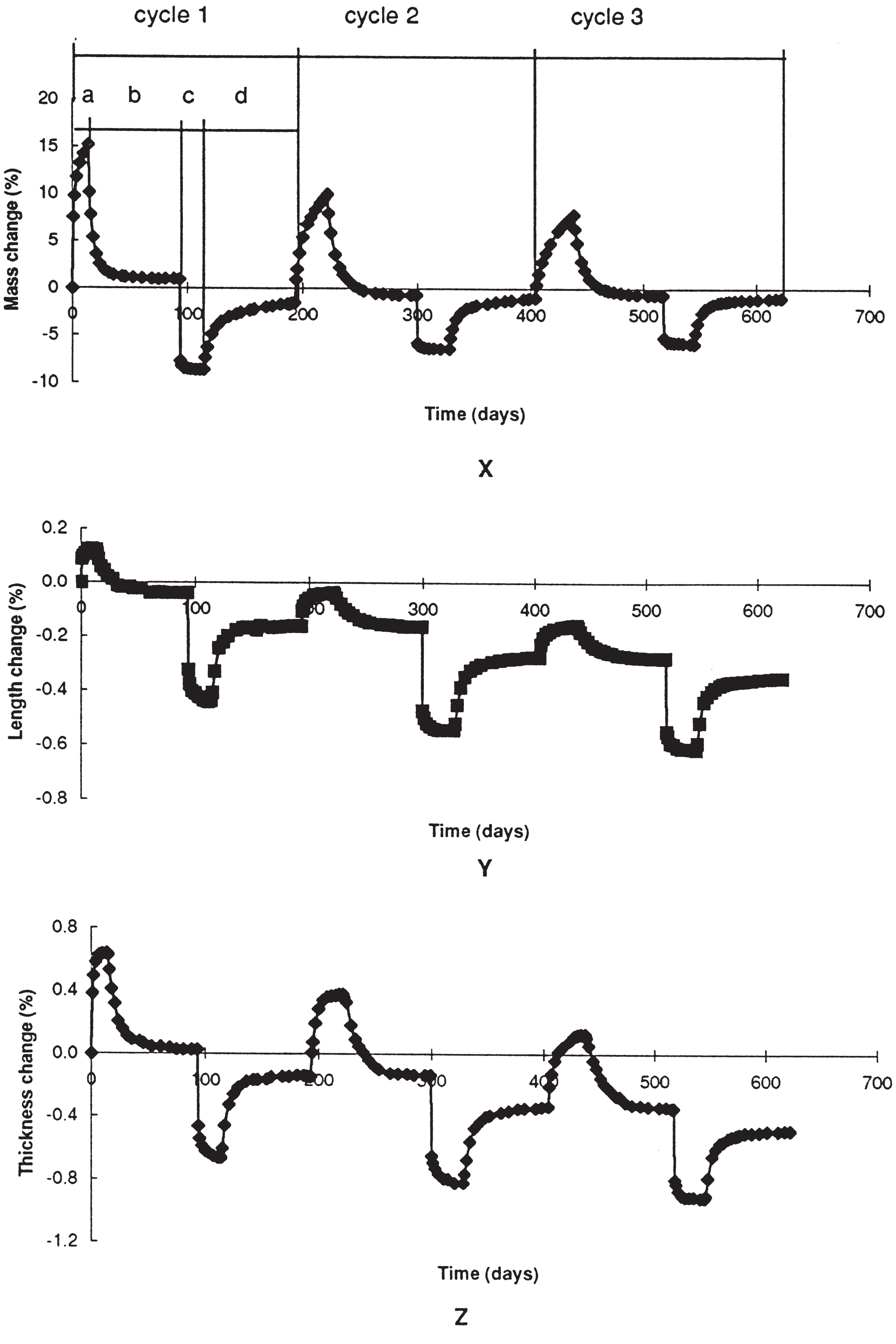

Fig. 2. Mass (X), length (Y), and thickness (Z) changes of CBPB exposed to wetting *(a)* 65% RH, *(b)* drying, *(c)* 65% RH, *(d)* cycle.

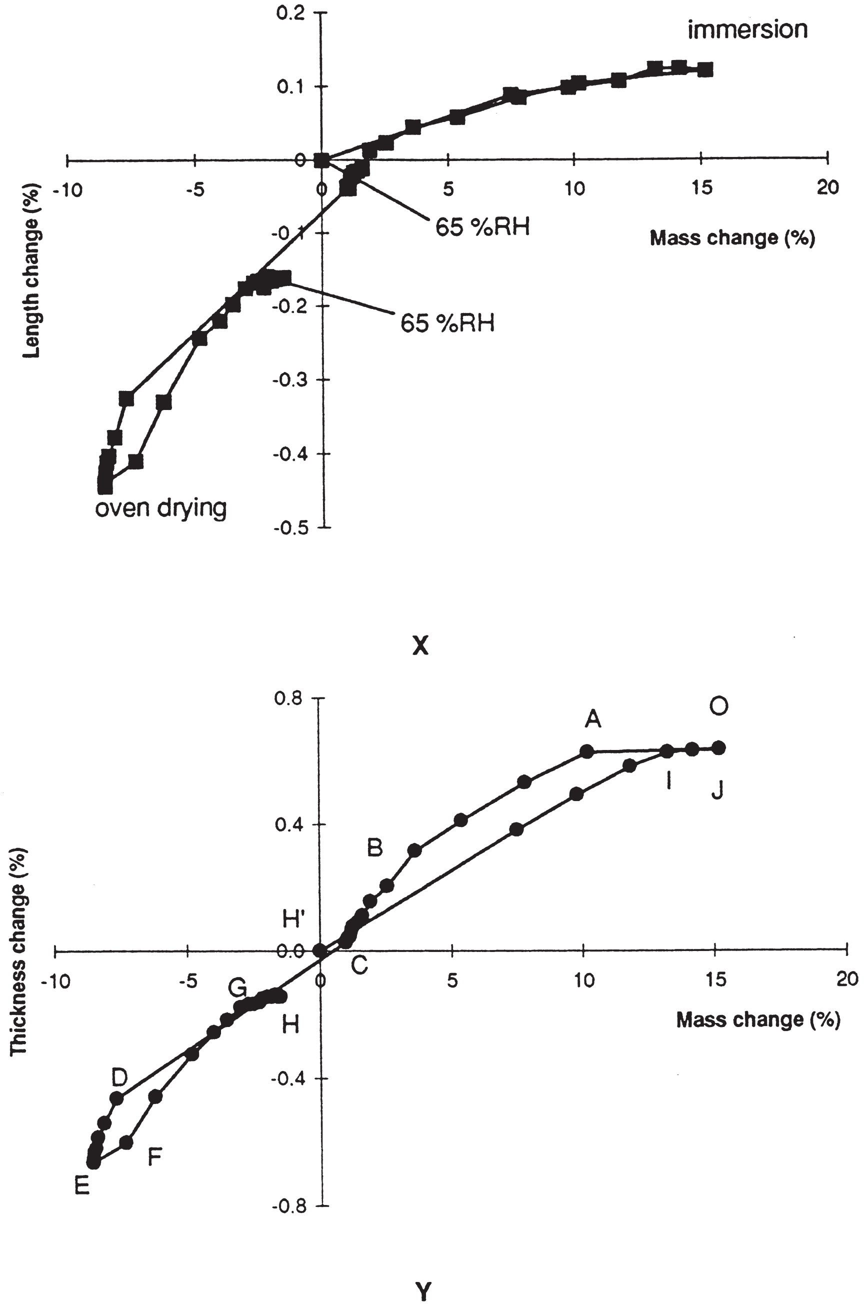

Fig. 3. Relationships between length (X) and thickness (Y) and mass change of CBPB cycling: 65% RH, soak, 65% RH, oven dry, 65% RH.

sponding volume change in both the wood chips and the adjacent cement paste.

2. Experimental evidence

Part of the results of a large and comprehensive investigation into behaviour of CBPB is set out below with a view toward examining the validity of these deformation mechanism theories. The relevant experiments are:

1. CBPB was subjected to sets of cycles—water soaking → 65% RH → oven drying → 65% RH—in order to examine the behaviour of CBPB over the whole range of moisture change.
2. CBPB was subjected to normal air and air devoid of CO_2 in order to evaluate the degree of carbonation from normal air exposure and its contribution to the deformation of CBPB.

2.1. Materials and procedure

Sample boards were removed from a factory procedure line. These boards were cut up to produce panels 600 × 300 × 18 mm. The edges of all panels were coated with two coats of epoxy resin. All panels were conditioned and stored at 20°C/65% RH before commencement of tests.

One group of specimens was subjected to the cycling regime shown in Eq. (3):

$$\begin{array}{c}\text{Water soaking }(20^\circ\text{C})\text{ -----}\rightarrow 20^\circ\text{C}/65\%\text{ RH -----}\rightarrow\text{Oven drying}\\ \uparrow\text{-----------------}20^\circ\text{C}/65\%\text{ RH -----------------}\downarrow\end{array}\tag{3}$$

The samples were moved from one condition to another after either constant dimension or constant mass was achieved.

A parallel experiment, under normal air and air devoid of CO_2, was designed for the other group of specimens (Table 2). The actual temperature and RH of the controlling chambers were monitored continuously and frequently calibrated. Three replicates were produced. Mass, length, and thickness were recorded after 24, 48, and 72 h and then at 72-h intervals. The changing values in mass and dimensions were converted into percentage changes with respect to the original values. The mean percentage change of the three replicates was used.

2.2. Discussion of test results

2.2.1. Desorption-adsorption

Fig. 2 shows that when CBPB was removed from water soaking and exposed to 65% RH, the mass and dimensional changes are rapid at the early stage of exposure, and slow down with time. Oven drying accelerates this process considerably. Reexposure to 65% RH results in rapid increase in both mass and dimension initially, but thereafter slowing down rapidly to an almost constant level that is much lower than the values on the previous exposure to the same RH (65%).

It is apparent that at the beginning of exposure to 65% RH, free water was released. This water was present in the cell lumens of wood chips or some large cavities in the cement paste and the interfacial area. This results in a considerable mass decrease, but only a slight decrease in dimensions (see Fig. 3). The process of movement of free water out of CBPB may continue for a certain period depending on the thickness and density of the CBPB, receding further from the surface into the centre of the CBPB. However, at the beginning of the exposure period the absorbed or bound water near the surface of the CBPB starts evaporating and brings about a substantial dimensional decrease. Such a slight change due to the movement of free water from deep in the CBPB is not reflected in the total change of values measured. Therefore, the duration of movement of free water is shown to be of short duration.

Drying absorbed or bound water from wood and from cement paste (gel water) should result in commensurate dimensional changes. This relationship is confirmed in Figs. 2 and 3, in which the linear relationships between mass and dimensional changes (Fig. 3) were produced in the second stage of exposure (on moving sample from water to 65% RH) and in the first stage of the exposure (on transferring samples from 65% RH to oven drying). The slight increase in the slope of lines for the relationship at the later stage of exposure to 65% RH indicates a slight increase in the mass of CBPB after long-term exposure. This is attributable to carbonation.

In Fig. 3, it appears that during the second stage of oven drying, removal of absorbed water in the CBPB results in a high shrinkage rate. This phenomenon, in theory, is not attributable to the shrinkage of wood chips, but to the mechanism of the deformation of the cement paste; the movement of water is thought to result in spontaneous closing of gaps, reducing intracrystal layer spacing.

Comparison of values in thickness change with those in length change (Fig. 2) indicates the significant effects of stresses generated by moisture gradient, the difference in structure along length and thickness directions, and the different nature of wood chips and cement paste.

In the reverse process, dry CBPB expands with increasing RH. In Fig. 3, regions F–G, G–H, and H′–I correspond to region C–D, B–C, and A–B in drying, respectively. The difference in magnitude manifests itself of different dominant mechanisms (irreversibility). Region E–F is the first stage of the adsorption where the mass increase did not bring about a commensurate increase in dimensions. This plateau indicates that there may exist another process that was thought to be due to the temperature change since the boards were removed from 100 to 20°C, causing a shrinkage in dimensions of CBPB.

A linear relationship (H′–I) at the early stage of water soaking indicates that the water probably was firstly absorbed by the wood cell wall and the gel pores of cement paste. Above the fibre saturation point of the wood chips,

Table 3
Mechanisms corresponding to the different stages of drying deformation

Stage*	Deformation	Dominant mechanisms
OA	Low shrinkage rate associated with high water loss	Capillary water
AB	Steady shrinkage rate (deformation linear with water loss)	Bound/adsorbed water
BC	Shrinkage rate increase due to the effect of carbonation	Bound/adsorbed water, carbonation and degradation
CD	Linearity between deformation and mass decrease	Bound/adsorbed water
DE	High shrinkage rate associated with small amount of water loss	Little adsorbed water and inter-/intracrystalline water, carbonation and degradation

* Referring to Fig. 3Y.

moisture increase will not bring about dimensional change. Hence, at this time the location of water in the cement paste is mostly in the capillary pores; this in turn results in less expansion compared to the removal of gel pore water, thus the slope of the graphs (region I–J) significantly decrease at the later stages of soaking. The duration of the first stage strongly depends on the structure of interface between the wood chip and the cement paste where the path of transverse flow may be blocked by the cement paste.

Therefore, the deformation of CBPB over a cycle—wetting → 65% RH → drying → 65% RH—comprised at least five distinct stages as summarized in Table 3, with each stage having different controlling mechanisms.

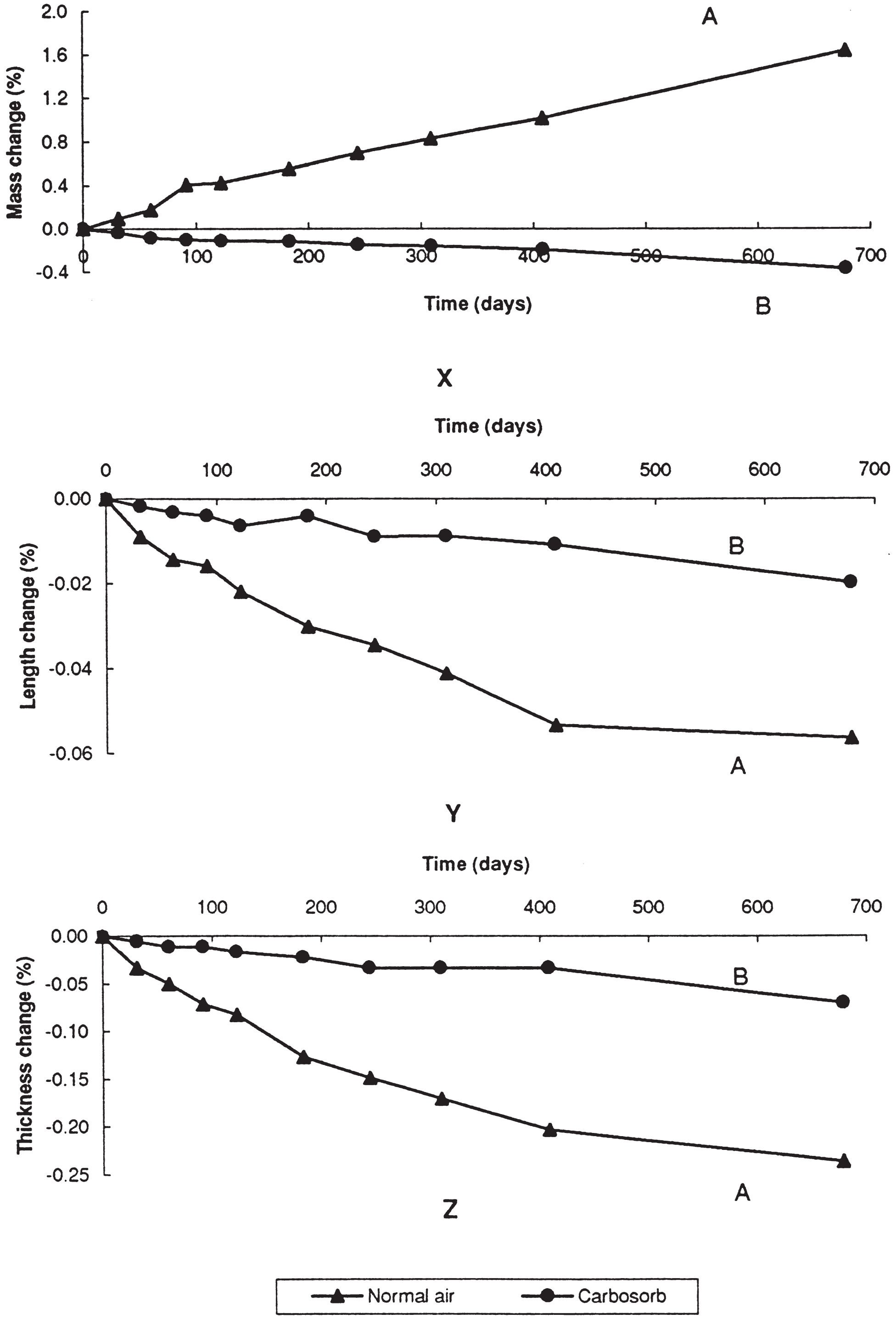

Fig. 4. Change in mass (X), length (Y), and thickness (Z) of CBPB under normal and CO_2-free air at constant 65% RH.

2.2.2. Irreversible shrinkage due to carbonation of CBPB

Carbonation and carbonation effects on CBPB under condition of constant RH of 65% are presented in Fig. 4. It is apparent that carbonation took place under normal air exposure; the mass of the CBPB consistently increased and the dimensions decreased. Over a period of exposure of about 680 days, the mass increased by about 1.64%, while the length and thickness decreased by about −0.06 and −0.24%, respectively. The slight decreases in mass and dimensions of CBPB subjected to the CO_2-free environment were possibly due to the degradation of wood chips and further hydration of cement paste. Therefore, changes due to carbonation were probably very slightly different from the values indicated. The value for mass change of CBPB should be equal at least to the addition of A and B. The values for length and thickness changes of CBPB due to carbonation should be given by B subtracted from A.

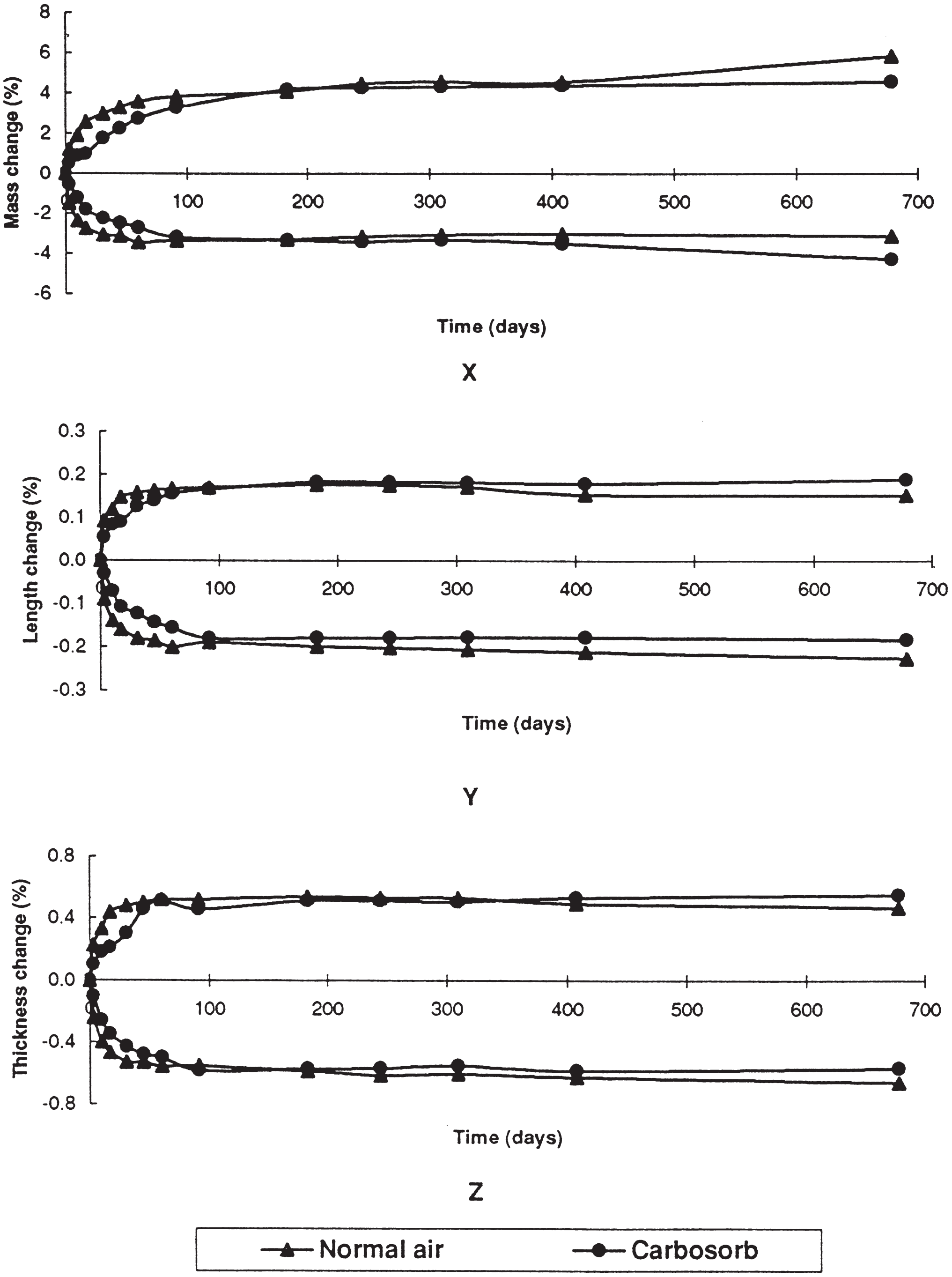

Fig. 5. Different changes in mass (X), length (Y), and thickness (Z) of CBPB under normal air and CO_2-free air on moving from 35 to 90% RH (curves above x-axes) and from 90 to 35% RH (curves below x-axes).

The results from the tests on CBPB under a single change of RH not only confirmed the presence of carbonation, but also indicated the contribution of CO_2 and moisture effect to the behaviour of CBPB. Fig. 5 presents the mass and dimensional changes of CBPB on moving from 90 to 35% RH and from 35 to 90% RH.

For desorption (the curves below x-axes of Fig. 5), it is shown that there was a divergence between the changes in normal air and air free of CO_2. Carbonation did not seem to occur at the beginning (or at least was much greater at later stages than that at early stage of exposure in moving sample from 90 to 35% RH). The difference in the behaviour between two stages of exposure is apparently due to different moisture profiles in the CBPB. Carbonation is accompanied by a release of water and time is required to extract water by drying. At the beginning of exposure, CBPB was nearly saturated though the ambient RH was 35% and the rate of carbonation was very low due to the low rate of carbon dioxide diffusion. This is in agreement with results on other cementitous materials observed by Schubert [14], who found that periodic rewetting significantly reduced carbonation due to a lower rate of carbon dioxide diffusion through the partially saturated pores of the cement paste matrix; and by Meyer [15], who concluded that variable moisture conditions can cause a change in the shape of the carbonation depth vs. time curve, with the rate of carbonation significantly decreasing with increase of moistening.

Comparisons of the changes under normal air with those under air free of CO_2 show that the behaviour of CBPB was due dominantly to the moisture change on moving from 90 to 35% RH. However, carbonation shrinkage had a significant effect on the total decrease in dimensions of CBPB at later stages of exposure (Figs. 3 and 5).

The rate of change in the early stages of exposure, whether in mass or dimensions, was very different between the two environmental conditions, with a much higher rate of change of CBPB under normal air than under CO_2-free air. The reason for this is still unknown. Very similar results were obtained on adsorption, as is illustrated in the curves above x-axes of Fig. 5.

Carbonation and induced carbonation shrinkage were also very significant when CBPB was subjected to a cyclic RH condition; this showed an accumulated increase in mass and decrease in dimensions when the number of cycles increased [2].

3. Conclusions

1. Movement of CBPB can be attributed to the combined effects of moisture reaction, carbonation, and degradation of CBPB; all of these parameters gave rise to the development of incompatible stresses that aggravated the effects of these parameters. The mechanisms, covering a wide range in RH, can be classified in two major categories: reverse and irreverse processes.
2. The deformation of CBPB over a cycle—wetting → 65% RH → drying → 65% RH—comprised at least five distinct stages, showing an association with the movement of different types of water, the features of both cement paste and wood chips, and the exposure environments. The plateau E–F (see Fig. 3) at the beginning of wetting is evidence of two opposite processes counterbalancing each other.
3. Irreversibility of CBPB due to carbonation was very significant and was accompanied by an accumulated increase in mass. However, carbonation and carbonation shrinkage were essentially dependent on RH and required the presence of water and an intermediate moisture content for maximum shrinkage. The values in the changes of CBPB due to carbonation may be implemented by the degradation of wood chips, which may reduce the mass and dimensions.
4. The decrease in the thickness of CBPB due to carbonation was much greater than that in length, suggesting that the difference between the change in length and thickness of CBPB under various exposures was not due solely to the structure and anisotropic nature of wood chips, but could also be affected by the generation of stress during the changes.

References

[1] M.Z. Fan, J.M. Dinwoodie, P.W. Bonfield, M.C. Breese, Dimensional instability of CBPB. Part 1 Behaviour and modelling prediction under constant and single changing RH, Wood Sci Tech (in press).

[2] M.Z. Fan, J.M. Dinwoodie, P.W. Bonfield, M.C. Breese, Dimensional instability of CBPB. Part 2 Behaviour and its prediction under cyclic change in RH, Wood Sci Tech (in press).

[3] M.Z. Fan, J.M. Dinwoodie, P.W. Bonfield, Dimensional instability of cement bonded particleboard, in: Proc. Inorganic-Bonded Wood and Fibre Comp. Mat., vol. 5, Forest Prod. Soc. Madison, WI, USA, 1997, p. 103.

[4] I. Soroka, Portland Cement Paste and Concrete, Macmillan Press Ltd., Basingstoke, England, 1979, p. 242.

[5] J.M. Dinwoodie, Timber: Its Nature and Behaviour, Van Norstrand Reinhold, England, 1981, p. 37.

[6] M.Z. Fan, Dimensional instability of CBPB: Understanding its occurrence and reducing its magnitude, PhD thesis, University of Wales, 1997.

[7] G.J. Verbeck, Carbonation of hydrated portland cement, Portland Cem Assoc Feb Bulletin 87 (1958) 17–36.

[8] T.C. Powers, A hypothesis on carbonation shrinkage, J Res Dev Labs Portland Cem Ass 4 (2) (1962) 40.

[9] A.V. Saetta, B.A. Schrefler, R.V. Vitaliani, The carbonation of concrete and the mechanism of moisture, heat and carbon dioxide flow through porous materials, Cem Concr Res 23 (1993) 761.

[10] W. Ahn, A.A. Moslemi, SEM examination of wood portland cement bonds, Wood Sci 13 (2) (1980) 77.

[11] N. Parameswaram, Microtechnological studies on mineral-bonded wood composite, Holzforschung 31 (6) (1997) 173.

[12] D.J. Steward, Interaction between ordinary portland cement and wood, PhD thesis, University of Wales, 1986.

[13] H. Roper, Dimensional change and water sorption studies of cement paste, Highw Res Bd Spec Rept 90 (1965) 9974.

[14] P. Schubert, Y. Efes, The carbonation behaviour of mortars and concrete, Proc RILEM Sym Paper 3 (5) (1976) 4 pp.

[15] A. Meyer, Investigation on the carbonation of concrete, Proc Chem Cem Tokyo 3 (1968) 394–401.