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Dimensional instability of cement bonded particleboard: *behaviour of wood chips from various stages of manufacture of CBPB*

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A technique for the dissection and measurement of wood chips used in cement bonded particleboard (CBPB) removed from the unpressed mat and the pressed board has been developed. The prepared chips were subjected to changing relative humidity (RH) conditions. The results illustrated the contribution of wood chips to the performance of CBPB. The trend in change of dissected chips was similar to that of CBPB but to a different degree under both a single and cyclic change in RH. However, the compression, contortion and chemical degradation of, and the inclusion of cement in, wood chips within CBPB resulted in an increase in mass change but decrease in dimensional change of dissected chips which were about 0.7, 3.0 and 1.3 times the change of raw wood chips respectively in mass, length and thickness over period tested. The combined effects of anisotropic characteristic, distribution and orientation of wood chips within CBPB brought about a significantly different ratio between length and thickness change of dissected chips to CBPB, having a ratio of about 2.5 for length and 15 for thickness. The nature of hysteresis loop for dissected chips was also very close to that of CBPB but dissimilar to that of raw wood chips.

Chips from the various stages of the production process showed very different responses to RH due to the effect of the processing parameters (pressure, curing temperature and time) on the nature of wood chips. The chips coated without any curing treatment were the most resistant to changing RH while raw wood chips had the greatest change in mass and the chips dissected from final product had the greatest change in dimensions. With the exception of raw wood chips, all types of chips showed a consistent increase in mass and a slight decrease in dimension with increasing number of cycles.

1. Introduction

As reported previously for CBPB [1, 2], changes in mass and dimensions of CBPB were considered to be the combination of changes in both the wood chips and the cement paste. It was considered necessary to run similar experiments for these two components in isolation in order to determine their relative contributions to the composite.

Moisture sorption and corresponding movement of normal wood has well been studied and interpreted [3–5]. The amount of “free water”, which has very little influence on the properties of wood other than its mass, is governed by the volume of the cell cavities and intercellular spaces, whilst the amount of “bound water” which has a considerable influence on the properties of wood, is detemined by the vapour pressure of the surrounding air. Generally, the removal of the bound water causes very small change in the longitudinal direction (about 0.1%), but a marked change in the radial and tangential directions (about 5% and 10% respectively). On the other hand, the volumetric change of wood beyond that produced by the presence of moisture can be very significant. Firstly, abnormal change due to incompatible stresses resulted from moisture gradients: this leads to a greater shrinkage in the transverse direction during drying [6] and a delayed width swelling compared to thickness swelling during adsorption [7]. Secondly, change may be due to mechanical restraint: under constant vapour pressure a compressive stress reduces sorption and a tensile stress increases sorption. If the swelling of dry wood is restrained by the influence of external forces the anatomical and molecular structure of the wood will be changed, hence it follows that subsequent re-drying to the original moisture content is accompanied by a reduction of the dimensions, i.e. by a permanent shrinkage, whilst a tension restraint in one direction of wood during drying resulted in a greater dimension in this direction than in the unrestrained wood [8, 9]. The effect of mechanical stress on shrinkage is most apparent when wood which is restrained from movement is subjected to cyclic moisture change [9]. For example, a temporary restraint on wood prior to nine wetting and drying cycles can cause a reduction of the dimensions by about 22% [8]. Thirdly, high swelling of wood may occur under strong alkalis: generally there exists a well-defined inter-relationship between volumetric swelling (beyond that in water) and the solution equilibrium pH [10]. Calcium hydroxide in CBPB has a significant effect on the swelling properties of wood, inducing increased rather than decreased wood moisture dimensional instability, and a small proportion of which was irrecoverable due to alkali hydrolysis of the wood [11]. Fourthly, change may be due to the effect of heating: heating, which may be experienced in the production of CBPB, will stabilize the dimension of wood, inducing a reduction in swelling and shrinkage. This may be accompanied by relatively large reductions in mechanical properties due to the thermal degradation of the most hygroscopic cell wall component [10, 12]. Fifthly, change may be due to the bulking of the cell wall: bulking may occur through the deposition of chemicals, or by chemical reaction with the cell wall, resulting in an increase in the volume of the dry cell walls and a reduction in the external volumetric shrinkage of the wood [10, 13]. Although the composition of the liquid phase in a hydrating cement is far from the ideal bulking agent due to the low solubility of the constituents, predominantly calcium hydroxide, sufficient calcium ions may be deposited within the cell wall due to its high affinity for alkalis to impart a degree of dimensional stabilization [11].

This present paper sets out the results and conclusions on the behaviour of dissected chips when subjected to the same climatic conditions as those used to evaluate CBPB [1, 2] in order to determine the contribution of wood chips to the dimensional and mass changes of CBPB. The paper also reports on the performance of wood chips removed at various stages of the production process to evaluate the effect of the processing parameters on the properties of CBPB.

2. Experimental materials and procedure

2.1. Preparation of wood chips

Five types of wood chips were investigated and are described in Table I. When selecting wood chips, three important criteria were considered: (A) the whole chip must not be damaged, in order to represent the nature of chips within the CBPB; (B) the chips selected must not be limited in size in order to enable a truly random distribution within the whole group of test samples to be obtained; (C) the shapes of isolated chips should not be specific.

TABLE I The types of wood chips used

Type	Name	Corresponding stage	Source
1	Raw wood chip	After flaking	Collected from storage tank
2	From the furnish chip	After mixing with cement and chemicals	Collected from mixing tank
3	Chip from edges of board	After 70–80 °C curing	Collected from edges of board coming out of first curing oven
4	Chip dissected from board	After 70–80 °C curing and cooled	Isolated from board without final oven drying
5	Chip from final product	After final oven drying	Isolated from final (commercial) products

Type 1. The chips of this type were removed from the chip storage silos.

Type 2. On removal from mixing tank these chips were wet, and the moisture content was determined. The chips were then placed in 20 °C/65%RH conditioning room before testing.

Type 3. When panels are coming out from the first curing oven (70–80 °C), chips were picked from the edges of panels. These were inspected to ensure that whole undamaged chips were tested.

Types 4 and 5. Boards of 600 × 300 × 18 mm CBPB were selected and cut into smaller sample sizes (50 × 50 × 18 mm); this dimension was chosen so that the whole chips could be obtained. This sample was then cut into slices 2 to 3 mm in thickness. The surfaces of these slices were assessed, those slices which contained chips whose surface was undamaged were retained and the surfaces scraped clean of cement paste. Slices with damaged chips were scrapped. A re-assessment of this chips was carried out after their dissection from the slice.

2.2. Exposure and measurement of chips

Mass measurement. The chips were placed on small, thin aluminum trays. Usually, a handful of chips was included in order to produce a measurable level of change in mass.

In the first hour of exposure to both initial conditioning and subsequent changes in RH, the chips were turned over several times to ensure relative uniform diffusion in moisture. The samples were weighed immediately prior to exposure, after 1 hour exposure, and then at 1–2 hour intervals until mass was constant, using an analytical balance with an accuracy of 0.001 g. All measurements were replicated three times, and the mean values were used.

Measurements of the length and width (thickness). Measurement was carried out under a travelling microscope fitted with a digital readout; the resolution was 0.0001 mm. In order to control the environmental

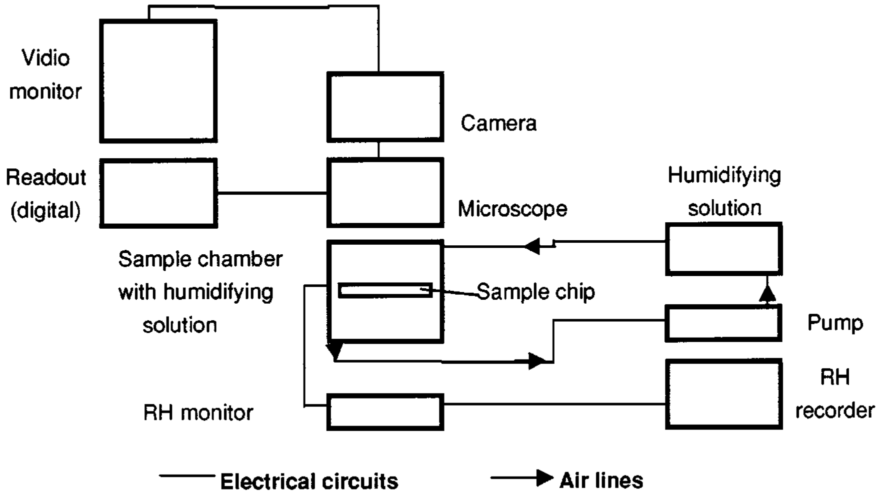

Figure 1 Diagram of apparatus used to expose wood chips to required RH environments and to measure their dimensional change.

conditions in which tests on the small size of chip samples could be carried out, a special test chamber was built, a diagram of which is presented in Fig. 1.

The testing equipment consisted of two main parts. One part is for chip measurement, incorporating a travelling microscopy, TV screen monitor and digital recorder. A second part is for chip exposure and contains the exposure chamber, the RH producing and calibrating chamber, and a chart recorder which kept a permanent record of the RH and temperature conditions within the exposure chamber.

For so small a size of chip, an important criterium when developing the test and which greatly influenced the results, was the positioning of the chips and the location of the measuring points. The samples had to be kept in one position and the same measuring points had to be ensured over the whole period of exposure. Therefore, the salt solutions, which were changed to produce changing RH, were held in a seperate RH producing chamber. The air of desired RH was circled between the two chambers by a pump. Another advantage of having a seperate RH producing chamber is to shorten the duration of RH recovery on changing it from one level to another. The sample was glued onto the slide with a single point of glue. The slide was fixed to the flat bottom of the measuring chamber.

The RH of the air within exposure chamber was kept at its required setting by saturated solutions of salts. The salts selected for the cyclic RHs are magnesium chloride, sodium nitrite and potassium acetate producing RHs of 35, 65 and 90% respectively. When the RH of the exposure chamber needed to be changed from one condition to another, the flow of air was stopped and the valve between two chambers was closed. The exposure chamber was sealed to maintain the previous RH condition until the new required environmental condition was achieved in the producing chamber (about 2 hours), when the movement of air was restarted.

From commissioning tests, it was found that the RH within the exposure chamber could be kept at the required values (i.e. 35, 65 and 90%RH). The sample was placed in the middle of the chamber to avoid possible corner effects. After a change in RH during cyclic exposure, the new RH level around the sample had reached about 80% of the required value after 1 hour, 90% after 2 hours and 100% after 4 hours.

To assess the moisture dimensional stability of chips on exposure to changing RH with a high degree of accuracy, it was necessary to carry out several measurements of each chip due to the very small value that is being assessed. Additionally, unlike the CBPB, because the effect of RH on the movement of the chips is significant and simultaneous, the interval between the measurements should be as close as possible to enable a better record of the behaviour of the chips to be obtained, especially at the beginning of exposure. For all the tests, the samples were measured after 1 hour and then at 1 to 2 hour intervals until constant.

3. Results and discussion

3.1. Behaviour of type 5 chips on both adsorption and desorption between 90 and 35%RH

Change in mass and dimensions of type 5 chips is displayed graphically in Fig. 2, which includes chips under both adsorption (moving chips from 35 to 90%RH) and desorption (from 90 to 35%RH). For ease of evaluation, the curves arising from type 1 chips and CBPB are all given on the same graph.

It appeared that the change in mass of type 5 chips was much lower than that of type 1 chips, but higher than that of the CBPB (Fig. 2A). The trends of the changes under adsorption and desorption followed those of the CBPB. The change in the mass of type 5 chips due to moisture change was only slightly different between adsorption and desorption. For all materials, the changes occurring in the early stages of exposure were very significant, but after a certain period the rate of the mass change markedly reduced. Under adsorption, further exposure of type 5 chips resulted in a consistent increase in mass. In contrast, the change in the mass of type 5 chips had a slight increase instead of decrease under a prolonged desorption. After 173 hours the changes in mass of type 5 chips

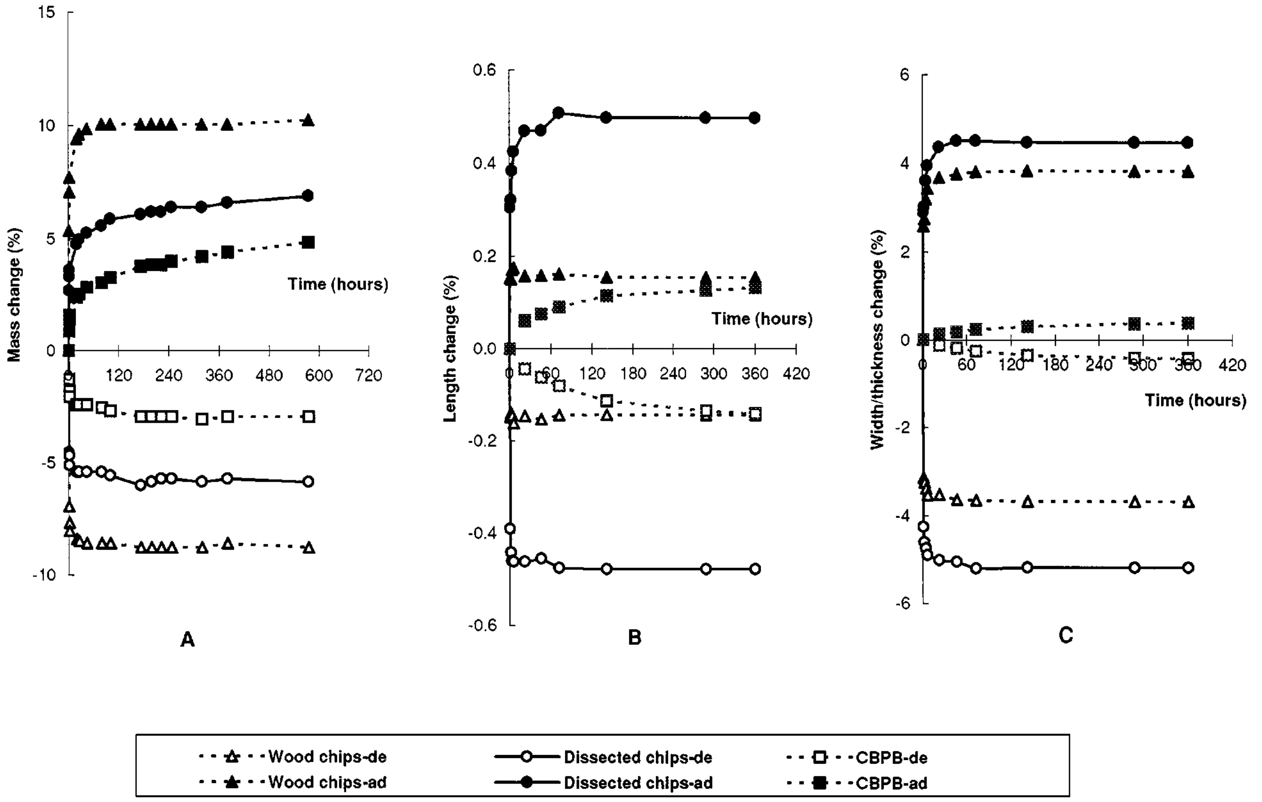

Figure 2 Change in mass (A), length (B) and thickness (C) of dissected chips (type 5), wood chips (type 1) and CBPB on moving from 35 to 90%RH and from 90 to 35%RH (de: desorption; ad: adsorption).

under adsorption and desorption were 6.07 and −5.86% respectively, while after 580 hours of exposure the values were 6.89 and −5.85%. This suggests that the liquid phase of the cement had (during manufacture) penetrated into the cell lumen (especially those of fractured cells), fractured cell walls or other checks and cavities, if not into the cell wall, which would have resulted in the bulking in the wood chips. This confirms the results presented by other authors [11]. Due to the inclusion of cement paste within wood chips, moisture condensation on the cement paste in type 5 chips under adsorption at 90%RH dominated the change in mass in the later stage of exposure. This resulted in a consistent increase, because the mini pores in the cement paste are able to hold a large quantity of water. Unlike the long term exposure of CBPB, the change of type 5 chips due to carbonation of cement paste embedded is negligible over the short term period of exposure. This can be confirmed by the plots arising from type 5 chips under desorption, in which the mass of type 5 chips reached a constant value.

It seems that the change in dimensions of type 5 chips are very different to those of type 1 chips and also CBPB as can be seen in Fig. 2B and C. However, some interesting facts and relationships emerge by a careful study of the graphs together with a consideration of the structure of CBPB and the degradation of wood chips under the alkali environment.

Firstly, the dimensional change of type 5 chips (under both adsorption and desorption) was higher than those of type 1 chips. This result was thought to be due to increased accessibility of moisture as a result of the high affinity of the cell wall hydroxyl groups for free hydroxyl ions, particularly in the lower ordered regions witin the cell wall, i.e. in areas of high hemicellulose and lignin content. This is in agreement with results found by Kollmann and Côté [8] and Steward [11], who found that calcium hydroxide had a significant effect on the swelling properties of wood, inducing decreased rather than increased dimensional stability.

Another explanation for the higher dimensional changes in type 5 chips than in type 1 chips was considered to be stress relief of individual type 5 chips contorted during fabrication, pressing and curing. 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 chips, this extended curing could result in stress on the wood chips.

Secondly, there were considerable differences in the changes in length and in thickness of type 5 chips compared to CBPB [1]. Over the time period investigated (about 360 hours), the change in length of type 5 chips (under both adsorption and desorption) was about 2.5 times higher than that of the CBPB. However, the width (thickness) change of type 5 chips was about 15 times higher than that of CBPB.

This difference can be explained by a combination of the structure of CBPB and the nature of wood. The length change of CBPB is determined not only by the longitudinal change of the chips but also by the transverse change of the chips. On the other hand, the thickness change of CBPB can be attributed not only to the transverse change, but also to the longitudinal change of the chips. Because of anisotropic characteristic of wood chips, the rate of change in length of CBPB increases while the rate of change in thickness of the CBPB decreases compared to the rate of the change of type 5 chips.

Thirdly, changes of type 5 chips, both in length and thickness, were much greater than those of CBPB. This was thought to be due to the bulking of the cell wall. It again illustrated that the behaviour of CBPB reflects the response of the chips and of the cement paste to the effect of moisture.

Fourthly, the higher change in dimensions of type 5 chips compared with type 1 chips contrasted with the lower change in the mass of type 5 chips compared with type 1 chips during exposure. This observation again reflects that during fabrication, the chips were penetrated with cement paste. An inclusion of cement paste increases the basic value of type 5 chips due to the much higher density of cement paste than that of wood chips, inducing a reduced change of total mass change at unit mass. Contrarily, the degradation of alkali solution may induce a decrease in the dimensional stability of type 5 chips.

Fifthly, the consistent increase in the mass of type 5 chips under adsorption at 90%RH did not occur in the dimensional change under the same exposure. The explanation of this lies in the effect of moisture condensation on the embedded cement paste.

CBPB should be considered as a two-phase material. The strain and sorption of the CBPB may be quantified in terms of the moduli and volume concentration of the two components. This will be discussed in the further paper in this series.

3.2. Behaviour of dissected chips under cyclic RH conditions

The mass and dimensional changes of type 5 chips under cycling RH is presented in Fig. 3. The values of the changes are based on the maximum values of type 5 chips under 90%RH.

Overall the same ranking order of mass, length and thickness changes occurred for type 5 chips and type 1 chips under cyclic RH as under a single change in RH. At various stages during cycling the RH, the change in the mass of type 5 chips was about half that of type 1 chips. However, for type 5 chips mass increased with increasing number of cycles regardless of their small size (Fig. 3A), as did CBPB [2]. This implies that a portion of the hydrated cement paste is lodged within type 5 chips, and that the chips inside CBPB might undergo structural change with cyclic RH change. Over 3 cycles the increase in the mass of type 5 chips (at 65%RH) was about 1.3% for desorption and 1.2% for adsorption.

Fig. 3B and C showed that, as for a single change in RH, the change in dimensions of type 1 chips was less than those of type 5 chips; the difference in change between type 1 and type 5 chips was more significant in length than in width (thickness) though with a similar trend. Overall, the change in the length of type 5 chips was about 2–3 times that of type 1 chips, while the change in the width (thickness) of type 5 chips was about 1.5–2 times that of type 1 chips.

With increasing number of cycles, a very slight decrease in the width (or thickness) of chips was observed at the end of 3 cycles (Fig. 3C). There does not appear to be any scientific reason for this and it may reflect a lack of sensitivity in the measuring equipment. The reason for the slight increase in length (Fig. 3B) over 3 cycles is unknown, though the hypothesis can be presented that the loosening of the structure due to cement penetration prevented recovery of the wood chips to their original dimensions during the cyclic RH exposure.

It was also observed that there was a different response of type 5 chips to different parts of the range in RH. High RH (90%) brought about a continual increase in the mass of type 5 chips. The change in the mass of type 5 chips in moving from 90 to 65%RH was less than that on moving from 65 to 35%RH. The rate in the change in transferring type 5 chips from 35 to 65%RH is lower than that from 65 to 90%RH. A similar relationship was found in dimensional changes over the range of RH exposed. During one complete cycle: 90-65-35-65-90%RH, the ratio of the change of type 5 chips was 1.0 : 1.2 : 0.9 : 1.6 for mass, 1.0 : 0.8 : 0.5 : 1.2 for width (thickness) and 1.0 : 0.7 : 0.7 : 1.3 for length. A complete examination of all these different responses of chips to cyclic RH indicates the nature of their contribution to the behaviour of CBPB.

It is clear that the difference in the changes of length and thickness (width) of type 5 chips under both a single and cyclic change in RH was mainly characterized by the anisotropy of wood although the total change could be supplemented by the cement paste embedded in it (observable in the thickness change (Fig. 4A and B)). Under both cyclic and single changes of RH, the maximum change of the width (thickness) is about 10 times that of the length change per unit mass change over both adsorption and desorption.

3.3. Relationship between dimensional and mass change of type 5 chips

The relationship between mass and dimensional change remained approximately linear for almost the whole range of adsorption and desorption, whether under a single (Fig. 4A and B) or cyclic (Fig. 5A and B) RH change. However, there was an indication that after a period of exposure, the mass increase did not result in a corresponding dimensional change of type 5 chips.

3.4. Sorption and dimensional change isotherms (hysteresis loops) of type 5 chips

The difference in the rate of change in mass between adsorption and desorption for type 5 chips (between 35 and 90%RH) gave rise to the existence of hysteresis loops. Fig. 6A shows a set of hysteresis loops of type 5 chips as a function of RH (solid line); for comparison, the hysteresis loops of type 1 chips derived from the same experimental condition are included in the

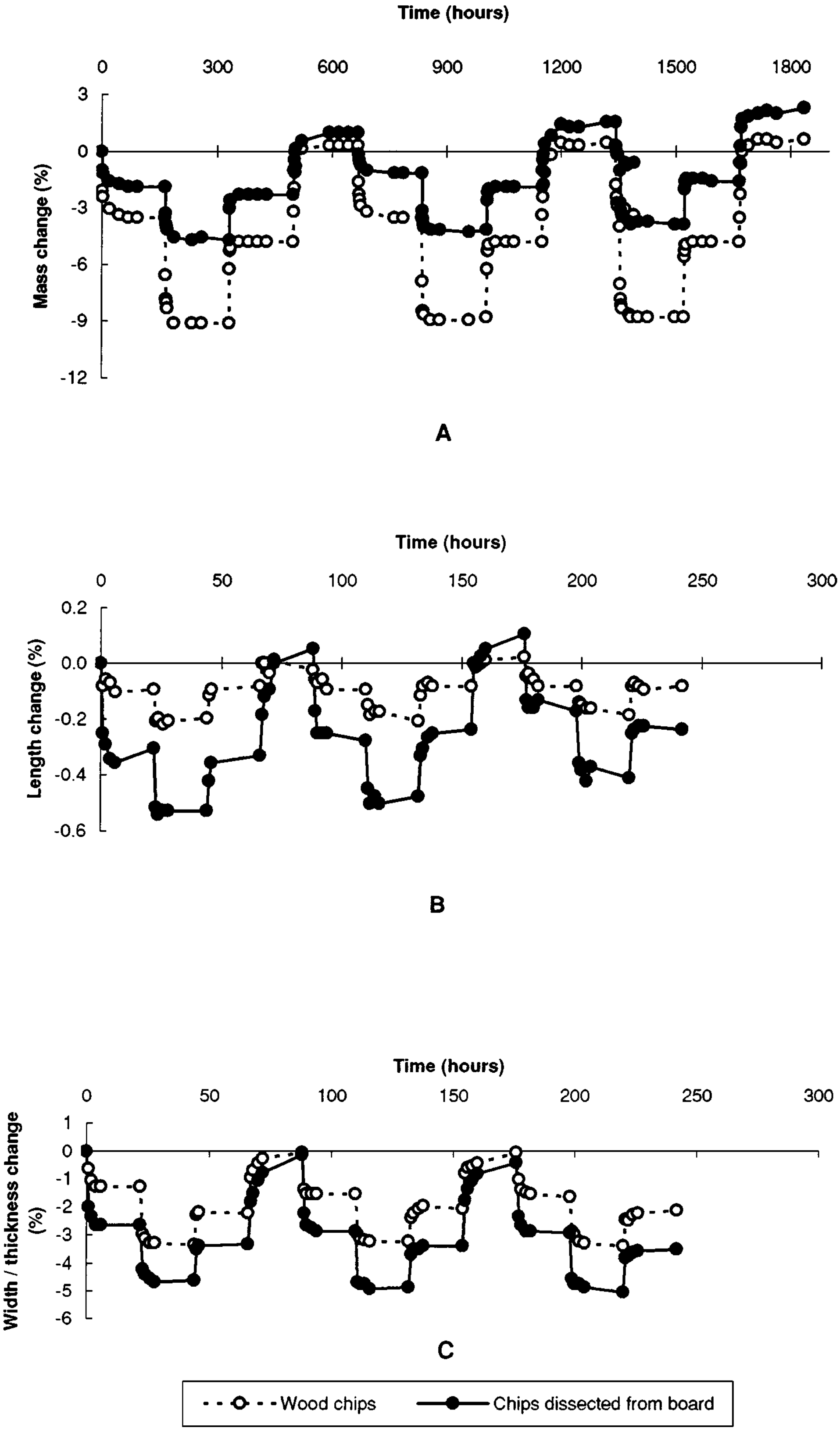

Figure 3 Mean mass (A), length (B) and thickness (C) changes of types 1 and 5 chips subjected to cyclic RH: 90-65-35-65-90%RH.

same graph (dotted line). The corresponding hysteresis loops for dimensional changes are presented in Fig. 6B and C.

In Fig. 6A, It is apparent that the hysteresis loops of type 5 chips are dissimilar to those for type 1 chips which arise in the nature of the response of wood, but are more similar to those of CBPB [2]. The similarities include:

(1) in each hysteresis loop, a gradual mass loss appeared on desorption, while the mass change on adsorption was more dependent of the level of the RH. The regain in mass under lower RH was slower than under higher RH. Hence, compared to the rate of mass decrease on desorption, the rate of regain in mass in moving type 5 chips from 35 to 65%RH was lower, while that from 65 to 90%RH was higher;

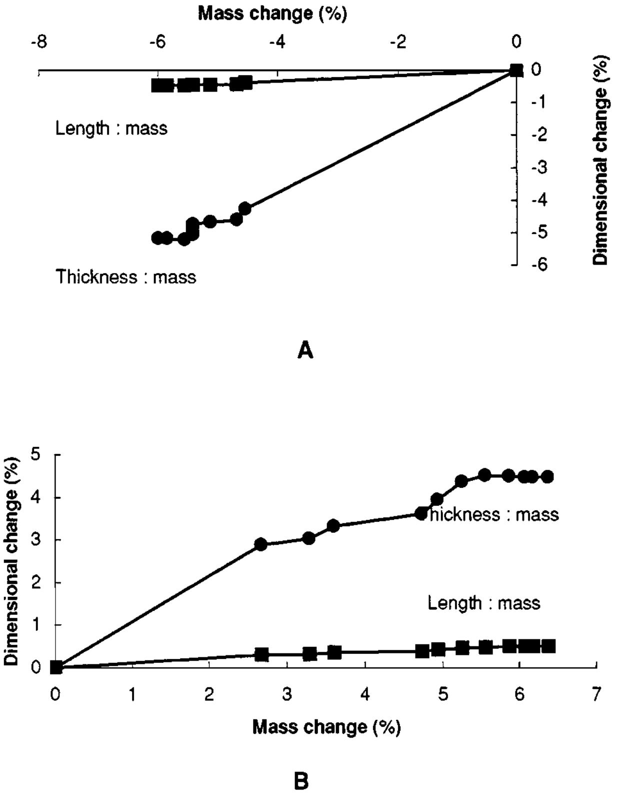

Figure 4 Relationship between dimensional and mass changes on moving type 5 chips from 90 to 35%RH (A) and from 35 to 90%RH (B).

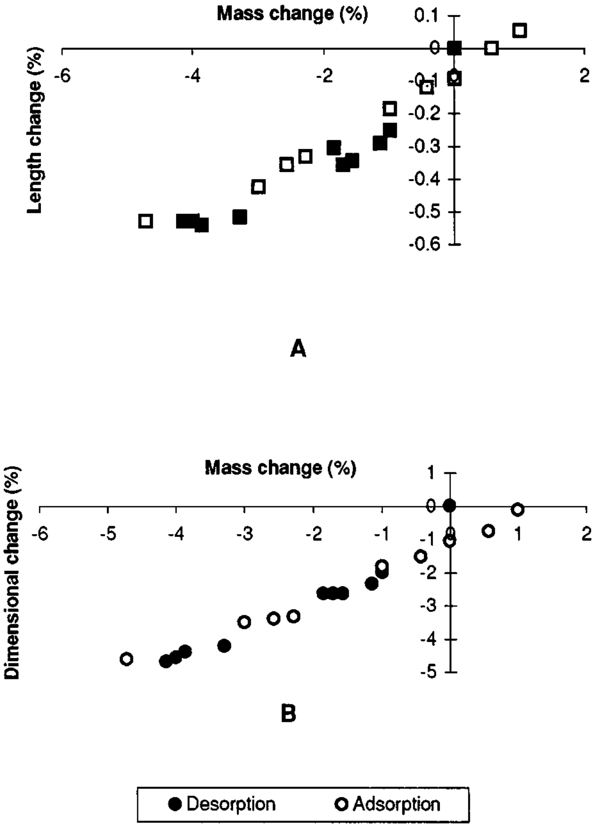

Figure 5 Relationship between length (A) and thickness (B) and mass change of type 5 chips within one complete cycle 90-65-35-65-90%RH.

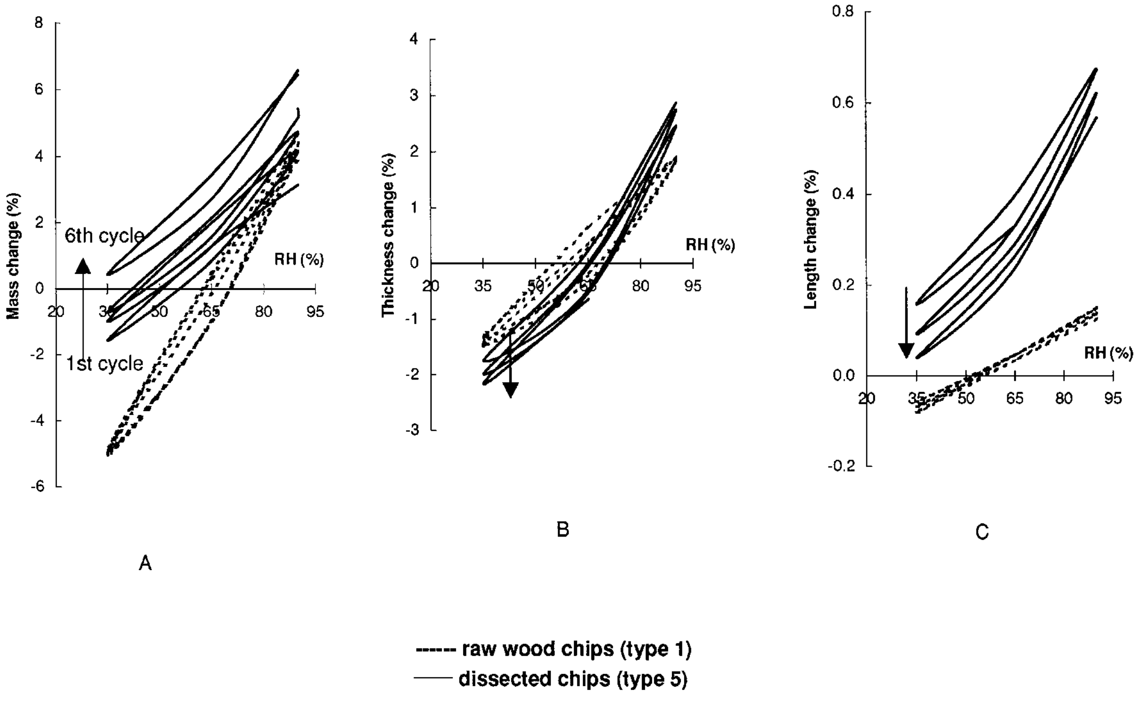

Figure 6 Hysteresis loops of mass (A), thickness (B) and length (C) changes of type 5 chips compared with those of type 1 chips.

(2) there existed an intersection between the adsorption and desorption curves. The location lies between 65 and 90%RH, depending on the cycles. In other words the loops do not close at the ultimate RH cycled, but the intersection divides the loops into two parts, one closed and another open;

(3) the isotherm curves within one complete cycle seem to follow the rule of the moisture reaction only for desorption and adsorption at lower RHs. The isotherm curve for adsorption at higher RH was influenced by moisture condensation;

(4) the area of the closed part of hysteresis loop increases with increasing number of cycles. In other words the intersection is approaching the extreme end of the RH cycled if type 5 chips are continuously cycled;

(5) the vertical movement of the hysteresis loop of type 5 chips was very clear. This suggests that the mass of type 5 chips increased consistently with successive cycles. At 90%RH, the increase in the mass of type 5 chips was 1.01 and 2.44% for the first three cycles and first six cycles respectively.

This similarity between CBPB and type 5 chips confirms the penetration of the cement paste into the wood chips. It strongly indicates that the embedded cement paste plays an important role in the mass change when type 5 chips are exposed to moisture change.

Comparison of the slope of the hysteresis loops arising from type 5 chips with those derived from type 1 chips shows a great reduction in the significance of the change in mass of type 5 chips. Alkali effects on the wood result in a higher swelling and mass decrease which are the reverse to the phenomenon above, such that the bulking of the cement paste could be the only explanation. The effect of bulking of cement paste is reflected in three ways: one is the restraint on the chip when it swells (normally much higher than cement paste); another is the higher density of cement paste increasing the basic value; and the third is the reduced moisture adsorption in unit mass of cement paste than in unit mass of wood chip over the range of RHs investigated (this is valid in the case without moisture condensation). This also makes it possible to explain the different relationship between the loops of type 5 chips and those of type 1 chips at low and high RHs (Fig. 6A); the loops of type 5 chips at 35%RH are much higher than those of type 1 chips, but at 90%RH are similar during the first several cycles.

It should be noted that the moving up of the loops of type 5 chips with increasing number of cycles may not only be caused by carbonation of cement paste embedded within the chips, but also be attributable to the further penetration of the cement paste, inducing expansion in the wood chips which may not be recovered on drying.

In addition to the specific changes in the mass, the features pointed out in Fig. 6A can be seen in the hysteresis loops arising from the thickness (width) changes of type 5 chips, Fig. 6B. The hysteresis loops of type 5 chips are moving downward as the number of cycles increases. The adsorption curves are not able to reach the desorption curves within one complete cycle, forming a open loop as that arising from CBPB [2]. Hence, compared to those arising from type 1 chips (which form a closed loop), the maximum width of the hysteresis loops derived from type 5 chips is narrower. It can be seen that there is an exception for the length change, in Fig. 6C. This was explained in terms of stresses relief as was recorded under a single change in RH.

The hysteresis loops arising from mass change, thickness change and length change are different compared to the corresponding loops of type 1 chips. The loops for the mass change of type 5 chips in the first three cycles are higher than those of type 1 chips only for a low range of RH; all other loops for mass change are significantly higher than those of type 1 chips. The loops for the thickness (width) change of type 5 chips are close to those of type 1 chips, with the loops arising from type 5 chips being lower under 65%RH, but higher 65%RH, compared to those arising from type 1 chips. The loops for the length change of type 5 chips are higher than those of type 1 chips over whole range of RH investigated.

3.5. Behaviour of wood chips removed from different stages in CBPB manufacture under cyclic RH

Five types of the chips from different stages of the production process (see Table I) were subjected to cyclic RH after two months storage at 20 °C/65%RH. The mass and dimension changes were examined.

The behaviour of these chips under a first adsorption at 90%RH is presented in Fig. 7. The change in mass and dimensions of the five types of chips during three cycles is provided in Figs 3 and 8.

3.5.1. The effect of the first adsorption at 90%RH

It appears that there is a very different response to moisture for the five types of chips. In Fig. 7A, the rate and amount of adsorption of type 2 chips was considerably lower compared to the other types of chips; while the rate and amount of adsorption for type 1 chips and type 3 chips was greatest. Increase in the mass of type 5 chips lay between them. Both types 4 and 5 chips showed very similar changes in mass.

For both types 1 and 3 chips, considerable adsorption occurs during the first 24 hours, and after about 40 hour exposure constant values were obtained for the mass change of type 1 chips. However, the increase in the mass of type 3 chips was consistent over the whole period tested. Other chips, type 2 or types 4 and 5, show a gradual change in mass over the whole range of RHs, though with a greater rate of change in the first stages than that at later stages (with the exception of type 2 chips, which only had a slightly increase during the later stage of exposure).

The observations above not only confirm the penetration of the cement paste (the diffusion of calcium hydroxide from the cement paste liquid phase) into the wood, which caused a delayed increase in mass compared to the change of type 1 chips, but also confirm the effect of temperature on the degree of degradation of wood. An additional explanation for the two extreme phenomena for types 3 and 2 chips is that after mixing, the surface of the wood chips were thoroughly covered with the cement paste and soaked with the liquid. Storage under 20 °C/65%RH resulted in a natural curing of the cement paste in the chips. In terms of shrinkage during curing, the higher the temperature, the higher is the size of the pores in heated cement paste under cure. Such type 2 chips not only are more integrated but also restrained by the covering stiff cement paste. When exposed to the moisture, it not only presented less space for the moisture, but also swelled less due to restraint. This brought about a reduced mass increase.

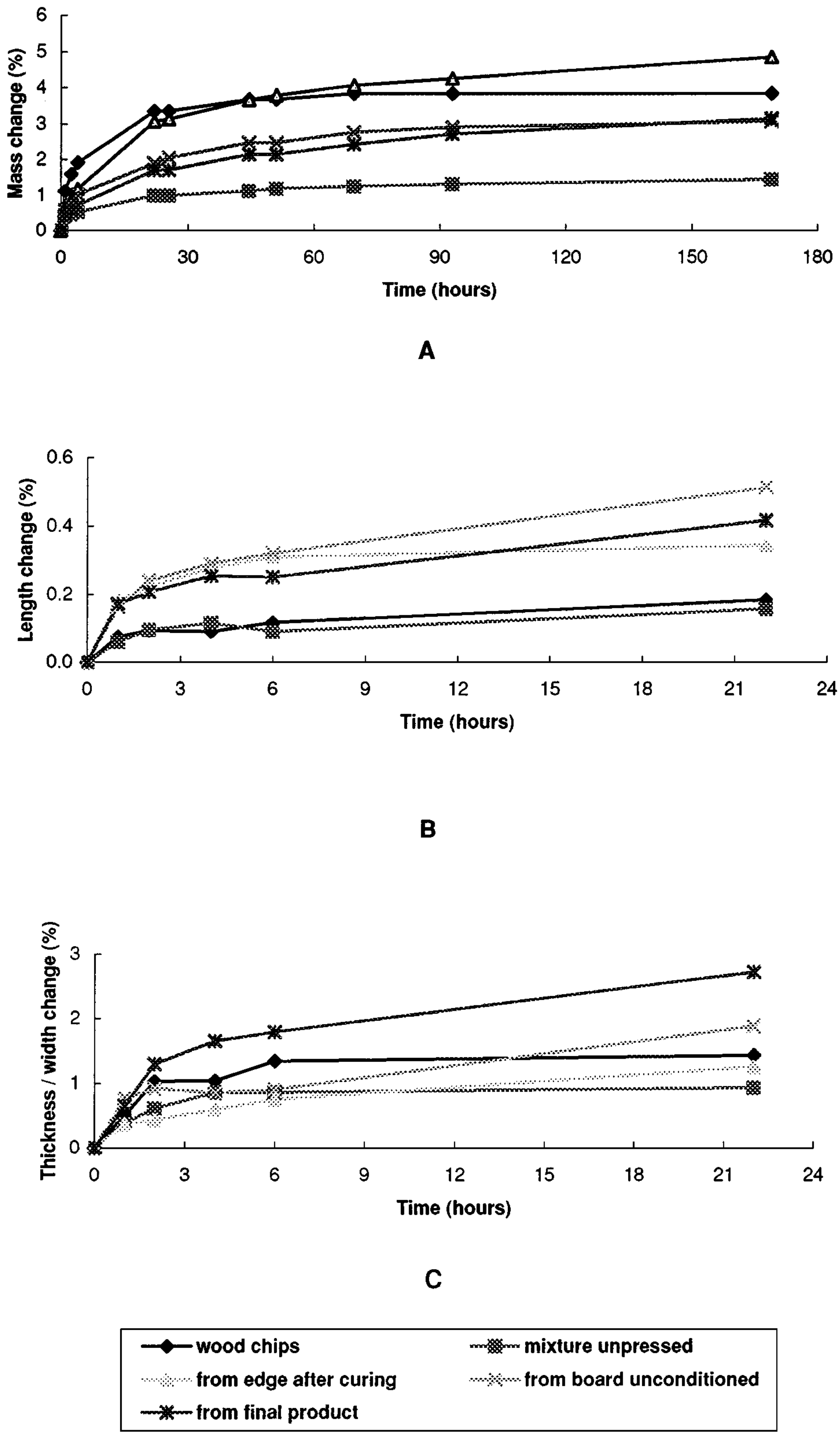

Figure 7 Mass (A), length (B) and thickness (C) changes of chips removed from different stages of production process under 1st adsorption at 90%RH.

The extreme high moisture adsorption of type 3 chips was probably due to both the amount of cement paste contained and the penetration of cement paste. Compared to type 2 chips, the penetration of the cement paste into these chips is very unlikely to be deeper due to the intensive curing during heating; compared to types 4 and 5 chips, the penetration of the cement paste into these chips is less, due to the pressure which did not affect the chips located on the edges but affected the chips inside the board. Less penetration of the cement paste makes this type of chip more representative of the nature of type 1 chips, resulting in a significant change of mass at first exposure, while the content of the cement paste made this type of chip change consistently in mass over the whole period of exposure.

A similar relationship can be seen for dimensional change (Fig. 7B and C) but with two exceptions: one of these is that dimensional change of type 1 chips was

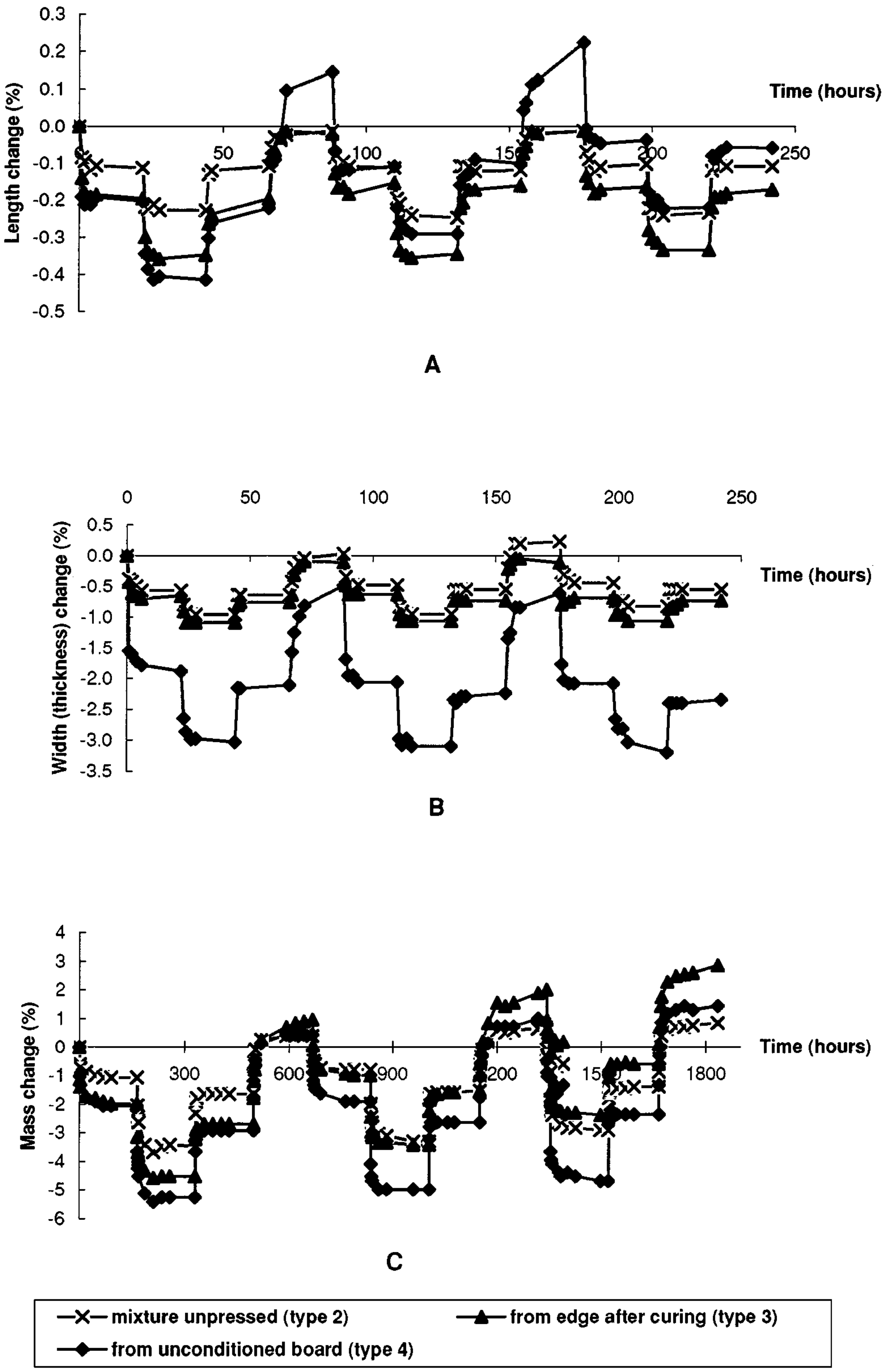

Figure 8 Mean length (A), thickness (B) and mass (C) changes of types 2, 3 and 4 chips subjected to cyclic RH: 90-65-35-65-90%RH.

lower than those of type 3 chips or of types 4 and 5 chips. This exception has been discussed in a previous section. The second exception is the dimensional increases in type 2 chips were less than those of type 1 chips. This confirms that type 2 chips are more compact and that the cement covering the outside of the chips may restrain the swelling.

It should be noted that the slight deviation between relationships of dimensional change and relationships of mass change amongst the various chips may be attributable to the sensitivity of the measuring equipment. However, deviation in the stress or contortion among the different types of chips could be one of the factors.

3.5.2. The response to cyclic RH

Generally speaking, the ranking order for the behaviour under cyclic RH between five types of chips is the same as those under first adsorption, with an exception for type 3 chips. There exists an unique characteristic for all types of chips excluding type 1 chips: all these chips exhibited a consistent increase in mass change with number of cycles, but not for type 1 chips (Fig. 3). The explanation of this has been provided in a previous section. Within each cycle, both mass decrease under desorption and mass increase in moving the chips from 35 to 65%RH were very similar between type 3 chips and type 2 chips. However, even after 3 cycles, the increase in the mass of type 3 chips was still very significant on transferring samples from 65 to 90%RH. The consistent increase of this type of chip between successive cycles is also most significant. These results indicate two characteristics of type 3 chips: the first is the dominant role played by the high percentage of the cement paste contained in this type of chips and the second is the loose structure of this type of chips.

The dimensional change of type 2 chips under cyclic RH was extremely low, as were type 3 chips. However, type 5 chips showed a large change in dimensions. This phenomenon may confirm one of the earlier assumptions, i.e. the higher dimensional change of type 5 chips compared to that of type 1 chips is due to the stress relief of the individual chips distorted during manufacture. It may also be attributable to the combined effects of high temperature and alkali.

It is apparent that in terms of the importance of the penetration of the cement paste, both the time after mixing and before pressing, and the pressure during pressing have a favourable influence on the stability of coated chips. Temperature could bring about a favourable effect on the flow of the cement paste liquid and shorten the curing period, consequentially changing the structure of the cement paste in the CBPB. The increase in the size of the pores on heating cement paste could result in less moisture adsorption under a normal service environment, but not under high RH, and this relationship may not have been appreciated in the past. The results on the components above confirmed the difference in response to RH change when assessed in terms of mass and dimensions. This manifested itself not only in terms of changing values with increasing number of cycles, but also in the fact the relative values for the various types of chips differ when expressed in terms of mass and dimensions.

4. Conclusions

(1) The change in the mass of type 5 chips, due to the moisture change under a single change of RH, lay between those of type 1 chips and CBPB, i.e. the change in the mass of type 1 chips > type 5 chips > CBPB panel. The nature of change on moving type 5 chips from 35 to 90%RH was close to that of CBPB, confirming that the cement liquid had penetrated into the cell lumens, fractured cell walls and other checks or cavities. Inclusion of cement paste in wood chips brought about a significant increase in the mass of type 5 chips at 90%RH due to the effect of moisture condensation.

(2) The dimensional changes arising from type 5 chips was higher than those arising from type 1 chips, suggesting that there was an increase in accessibility of moisture as a result of the high affinity of the cell wall hydroxyl groups for free hydroxyl ions, and/or there was stress relief of the individual wood chips which had contorted during fabrication, pressing and curing. Over the time period investigated, the change in length of type 5 chips was about 2.5 times higher than that of the CBPB, but about 15 times higher for width (thickness).

(3) Overall the same ranking order of mass, length and thickness changes occurred between type 5 and type 1 chips under cyclic RH as under a single change of RH. At various stages of RH, the change in the mass of type 5 chips was about half that of type 1 chips, while the change in the length was about 2–3 times higher, and the change in the thickness (width) was about 1.5–2 times higher than those of type 1 chips. However, there existed a different response of type 5 chips to different parts of the range of RHs and to different histories of sorption.

(4) As the number of cycles increased, the mass of type 5 chips increased consistently while the width (thickness) decreased slightly, again implying the inclusion of cement paste into type 5 chips. The slight increase in length was thought to be due to the loosening of the structure of type 5 chips.

(5) The hysteresis loops of type 5 chips were dissimilar to those of type 1 chips (which were the same as those of solid wood). There was a great reduction in the significance of the mass change of type 5 chips in terms of both slopes and width of the loops; this reflected the effects of bulking of the cement paste. The hysteresis loops of type 5 chips were also located differently, depending on the mass, length or thickness, and on the range of RH. However, the loops of type 5 chips were much more similar to those of CBPB.

(6) Chips from the various stages of the production process show very different responses to RH. Generally, type 2 chips were the most resistant to RH change in terms of both mass and dimensions. In type 1 chips the highest change occurred in mass, while in type 5 chips the highest change occurred in dimensions. Type 3 chips were very sensitive to high RH (90%), showing substantial increases in mass due to the percentage of cement paste. However, the change under desorption and adsorption over lower RH was similar in behaviour to those of type 2 chips.

(7) All types of chips but excluding type 1 chips, showed a consistent increase in mass and a slight decrease in the thickness (width) with increasing number of exposure cycles.

(8) Considering the effect of processing parameters, the results confirmed that the time after mixing and pressure during pressing had a favourable influence on the behaviour of the chips due to increased penetration of the cell wall or lumen by the cement paste; temperature had an effect on the structure of cement paste in CBPB.

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