Ageing effect and long term performance of cement bonded particleboard

Prepared for: *Viroc Portugal – Indústrias de Madeira e Cimento S.A.*

25 March 2008

Client report number 225399

Prepared by

Name Dr Mizi Fan

Position Senior Consultant

Signature *Mizi Fan*

Approved on behalf of BRE

Name Dr Ed Suttie

Position Director, Timber

Date 31.3.08

Signature

BRE
Garston
WD25 9XX
T + 44 (0) 1923 664000
F + 44 (0) 1923 664010
E enquiries@bre.co.uk
www.bre.co.uk

Executive Summary

Upon request from Viroc (Portugal), BRE carried out an investigation specifically for Viroc CBPB, in order to evaluate the ageing effect on the strength, stiffness, mass and dimension of Viroc CBPB under long term exposure.

The study was carried out in two stages:

Stage I: Six month investigation on the ageing effect and performance of CBPB

Stage II: Further one year investigation on the ageing effect and long term performance of CBPB

The results from Stage I showed that

1) Both strength and stiffness of Viroc CBPB were increasing consistently although the test results showed much better performance than those required in EN standards.

2) Mass of Viroc CBPB consistently increased and dimension decreased.

After reviewing the Stage I report and test results, Viroc had decided to carry out further tests and monitoring. The overall results have confirmed that:

3) Physical and mechanical properties of CBPB changed with the exposing duration of 48 months tested, as discussed ‘1)’ and ‘2)’

4) There is great potential for Viroc CBPB in terms of both the production and uses of the product

5) Exposure environmental conditions (where materials to be used) had significant effect on performance of CBPB in uses. These are of importance when design and selection of Viroc CBPB.

6) Carbonation and further hydration of Viroc CBPB may be important factors for consistent physical and chemical changes of CBPB.

7) Design and selection of CBPB based on current available design values or standards may not be reliable accurate, whether overestimating or underestimating the performance of CBPB.

Contents

Introduction

Cement bonded particleboard (CBPB) is a unique material. Unlike other wood based panels, the structure and consequently strength and dimensions consistently change even under normal air environments. Uses of CBPB have been limited due to insufficient information of its nature.

Upon a request from Viroc (Portugal), BRE firstly agreed to carry out an investigation specifically for Viroc products for six months' duration, in order to evaluate the ageing effect under long term exposure.

The study was firstly to carry out a calibration test of CBPB, and then to determine/understand the strength change of Viroc CBPB. In parallel, dimensional change of CBPB in corresponding with the strength changes was also examined. Additional tests for stiffness, carbonation depth and mass change were also carried out.

However, after reviewing the outcomes from the first six month study, Viroc Portugal has valued potentials of their products and considered it necessary to continue the programme for another year. Therefore, stage II assessment programme was set up.

This report describes the test results and discusses the possible reasons causing the changes in strength, stiffness, mass and dimensions. The results combine those of stage I and stage II investigations.

Description of the project

1 Objective

Overall objective of this study was to understand the strength, stiffness, mass and dimensional changes of Viroc CBPB under short- and long-term exposure.

2 Tests

The following properties are considered most relevant and important based on BRE's experience, and therefore are included in the programme:

1 Short term properties of Viroc CBPB

2 Change in strength of Viroc CBPB

3 Change in stiffness of Viroc CBPB

4 Change in mass of Viroc CBPB

5 Change in dimensions of Viroc CBPB

6 Depth of carbonation of Viroc CBPB

3 Exposure conditions

Changes in both **strength and stiffness** were studied for Viroc CBPB subjected to:

i) Air devoid of CO_2

ii) Normal indoor air of 20°C/65% relative humidity

iii) Normal outdoor air protected

iv) Weathering exposure

Exposure conditions of 'i)' and 'ii)' allow to study the effects of both further hydration and carbonation of Viroc CBPB.

Changes in **mass and dimensions** were studied for Viroc CBPB subjected to:

i) Air devoid of CO_2

ii) Normal indoor air of 20°C/65% relative humidity

In common with wood based panels, mass and dimension are sensitive to moisture and temperature. The purpose of this study is to investigate the unique nature of CBPB, to understand the occurrence of property changes, therefore constant conditions are essential.

4 Materials and methods

190 test pieces were prepared by Viroc. The size of test pieces: length x width x thickness = 430 x 50 x 16 mm. These were for testing strength, stiffness, mass and dimensional changes. The criteria for sampling test pieces include:

i) All test pieces were cut IMMEDIATELY after production (after conditioning of production line), that is totally from fresh board.

ii) Test pieces were marked in order, that is all side matched one after another.

iii) Test pieces were sealed on all FOUR EDGES by 2 coats of epoxy but NOT top and bottom surfaces (that is, only top and bottom surfaces unsealed)

iv) As soon as sealant was dry (normally one coat a day), all test pieces were wrapped in order to isolate them from air contact (e.g. by using plastic film, etc.).

Upon the receipt of Viroc CBPB, BRE allocated the test pieces as Table 1. This was to ensure a consistency in the properties of fresh CBPB for various exposures, and comparable test results.

50 test pieces, with dimensions of 50x50x16 mm, were also prepared for IB strength and carbonation tests at BRE.

Table 1 Allocation of test pieces

Initial test	Free CO2		Indoor 20C/65%rh		Outdoor protected	Weathering	Stage
2	1		3		4	5	I
7	6	10	8	11	12	13	I
9	15	18	16	19	20	21	I
14	23	26	24	27	28	29	I
17	31	34	32	35	36	37	I
22	39	42	40	43	44	45	I
25	46	48	47	49	50	51	I
30	52	54	53	55	56	57	I
33	58	60	59	61	62	63	I
38	64	66	65	67	68	69	I
41	70	72	71	73	74	75	I
	76	78	77	79	80	81	I
	82	84	83	85	86	87	I
	88	90	89	91	92	93	I
	94	96	95	97	98	99	I
	100	102	101	103	104	105	I
	106	108	107	109	110	111	I
	112	114	113	115	116	117	I
	118	120	119	121	122	123	II
	124	126	125	127	128	129	II
	130	132	131	133	134	135	II
	136	138	137	139	140	141	II
	142	144	143	145	146	147	II
	148	150	149	151	152	153	II
	154	156	155	157	158	159	II
	160	162	161	163	164	165	II
	166	168	167	169	170	171	II
	172	174	173	175	176	177	II
	178	180	179	181	182	183	II
	184	186	185	187	188	189	II

Findings

1 Properties of fresh CBPB

Both physical and mechanical properties of CBPB were evaluated by the manufacture and BRE (as received). The mean values of the results are given in Tables 2 and 3. Test data for each individual test pieces are given in Annex A.

Table 2 Moisture content of CBPB

	MC (1 day drying) (%)	MC (1 day + 6 hours drying) (%)	MC (1 day + 72 hours drying) (%)
From Supplier			
Mean	7.7-9.3	x	x
Tested at BRE			
Mean	10.39	10.48	10.97
stdev	0.39	0.40	0.55
cov (%)	3.77	3.78	5.05

Table 3 Properties of fresh CBPB

	MOR (N/mm^2)	MOE (N/mm^2)	Density (kg/m^3)	IB (N/mm^2)
Tested at BRE				
Mean	10.62	x	1354.37	0.84
stdev	0.59	x	68.21	0.08
cov (%)	5.57	x	5.04	9.98
From Supplier				
Mean	9.00	5910.00	1228.00	x

A comparison of moisture content tested at BRE with that supplied by Viroc indicates that air may have penetrated into the material during transportation. This means that the CBPB could undergo further hydration if there is any and carbonation. Both density and strength of CBPB may increase.

2. Strength and stiffness of CBPB

Our experiences show that CBPB is a unique material. There is a great potential to exploit its capacity if the nature of material is fully understood. However, equally it has a safety implication for over- or under-estimating the capacity of CBPB.

CBPB may undergo a consistent change in both strength and dimensions. For the specific Viroc products, the limited tests have been carried out at BRE and an overall strength increase is given in Tables 4 and 5.

Table 4 An overall increase in MOR of Viroc CBPB tested (N/mm^2)

Exposure time (month)	Indoor exposure	Weathering
0	10.62	10.62
1	10.99	x
2	10.81	10.28
4	12.40	9.90
6	13.10	10.50
9	13.44	11.43
12	14.00	12.89
18	14.89	13.98
48	15.11	14.33

Table 5 An overall increase in MOE of Viroc CBPB tested ($x1000N/mm^2$)

Exposure time (month)	Indoor exposure	Weathering
0	5.91 (from Viroc)	5.91 (from Viroc)
1	5.31	x
2	5.82	5.52
4	8.81	6.90
6	8.63	7.11

9	9.02	7.89
12	9.41	8.88
18	10.08	10.68
48	10.89	11.03

It is apparent that the structure of Viroc CBPB may have changed by comparing fresh CBPB with those under various durations of exposure. More detailed experiments have been carried out to evaluate the contributors. These include:

2.1 Further hydration

It has been approved from the test (first six months) that an increase in the strength and stiffness of Viroc CBPB may be in part due to the further hydration of CBPB. A summarised test result for CBPB exposed devoid of CO_2 is given in Table 6.

Table 6 Mean strength and stiffness of CBPB under free-CO_2

Exposure time (month)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm2)	Density (N/mm^3)
0	10.62	5910	0.84	1324
1	10.86	4808	x	x
2	10.35	6389	x	x
4	10.80	6551	x	x
6	11.21	6721	0.83	1338

Hydration of CBPB is conditional on the present of water which is readily available from the adjacent wood chips embedded in CBPB or from the surrounding environment. Further hydration of CBPB increases the solid content of the cement paste in CBPB, and this increase will also increase the volume of gel pores at the expanse of capillary pores, producing higher strength and density of CBPB. From the tested values, the strength of Viroc CBPB increased by about 6% after 6 months exposure, the stiffness increased by about 14% and the density increased by about 1%.

It should be noted that an increase in the gel pore could result in a higher shrinkage and moisture absorption.

2.2 Carbonation of CBPB

The contribution of carbonation to the strength of CBPB is examined by exposing the CBPB under both the air devoid of CO_2 for six months and normal air environment in parallel. Summarised results are given in Tables 7 and 8.

Table 7 Average changes in strength of CBPB (N/mm^2)

Exposure time (month)	Free CO_2	Normal air of 20°C/65%rh	Difference
0	10.62	10.62	0
1	10.86	10.99	0.13
2	10.35	10.81	0.46
4	10.80	12.40	1.60
6	11.21	13.10	1.89

Table 8 Average changes in stiffness of CBPB (N/mm^2)

Exposure time (month)	Free CO_2	Normal air of 20°C/65%rh	Difference
0	5910	5910	0
1	4808	5039	231
2	6389	5820	569
4	6551	8005	1454
6	6721	8628	1907

If there had not been the combined effect of further hydration and carbonation, the increase in the strength of CBPB due to carbonation was about 18% compared to the strength of fresh CBPB after 6 months exposure (Table 7), and increase in the stiffness was about 32% (Table 8).

The effect of carbonation on the strength can be further verified by the depth of carbonation with time (see Figures 1-4).

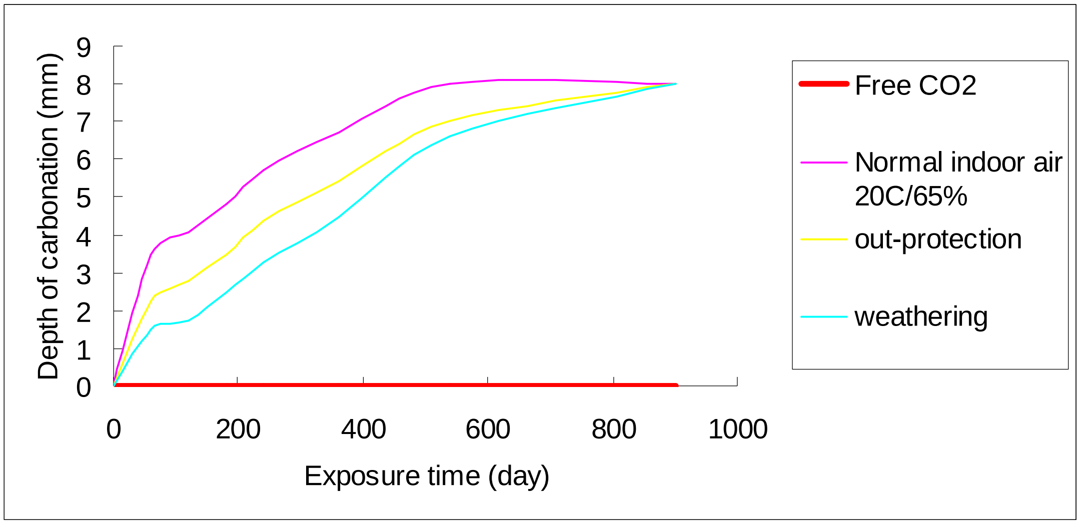

Figure 1 Mean depth of carbonation of Viroc CBPB with time under various exposure conditions

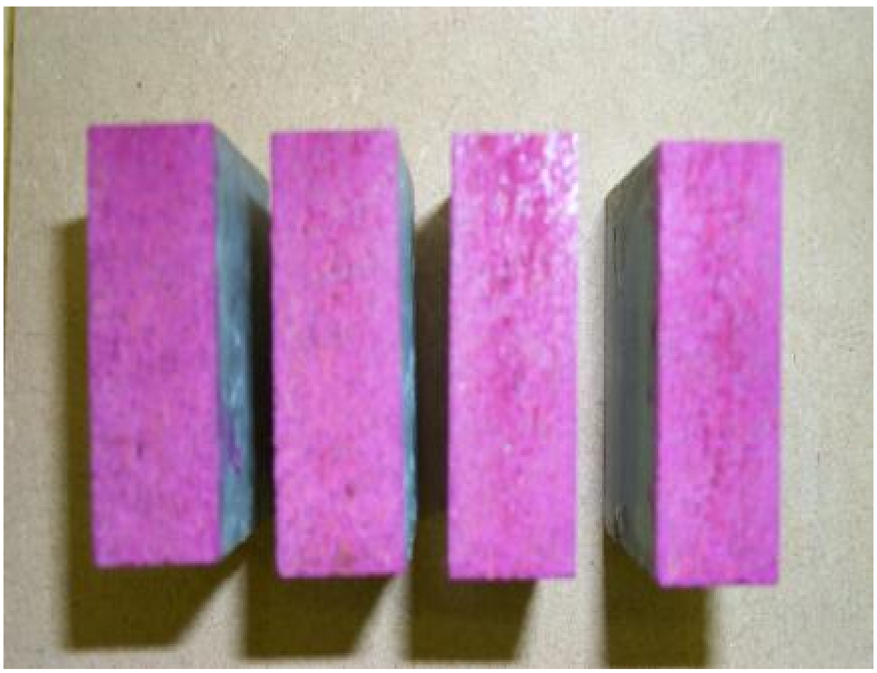

Figure 2 Fresh CBPB before exposure

Figure 3 Carbonation of Viroc CBPB after 2 month exposure (from left to right: Free CO_2→normal air→outdoor protected→weathering exposure)

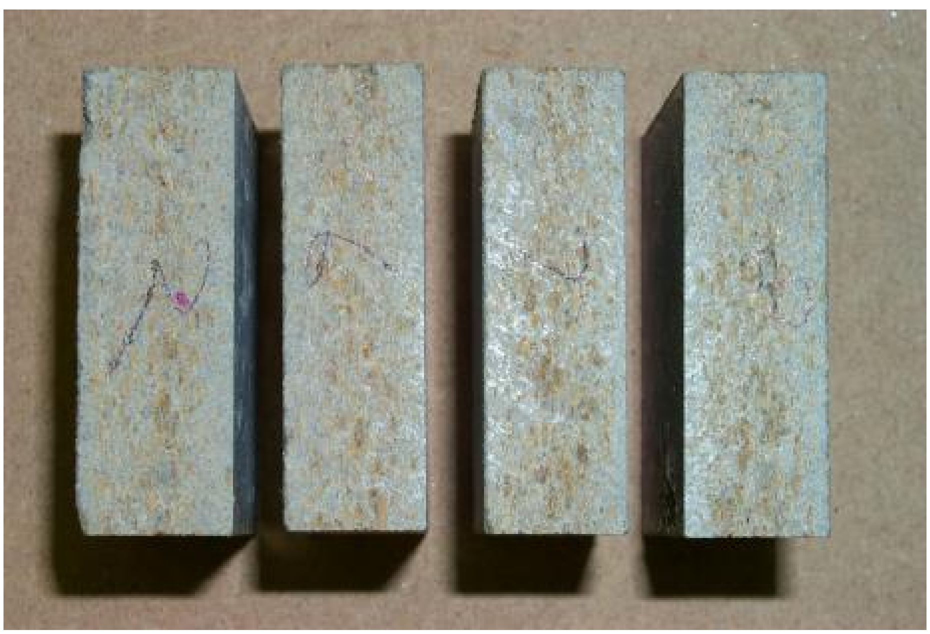

Figure 4 Fully carbonated Viroc CBPB after 2 year's exposure under normal indoor air environment

Figure 1 shows that the depth of carbonation of CBPB increased with the increase of time under various environmental conditions except for free CO_2 exposure. Substantial carbonation can occur even at the low CO_2 concentration normally found in the atmosphere. It is not limited to the hydroxide present, but is also associated with other components in CBPB. The resulting modification of the cement gel in CBPB is reflected in the changes in properties (see Tables 7 and 8). However, the most dramatic effect of carbonation of CBPB is a large increase in shrinkage under intermediate conditions, see next section.

It can be seen from Figure 3 that the carbonation proceeded from 3-D. The rate of carbonation is more significant from the edges than from surfaces of the CBPB (Figure 3). There was no carbonation for CBPB under air devoid of CO_2.

The duration of carbonation for the CBPB tested was about 1.5 year (Figures 1 and 4)

2.3 Effect of exposure environments

The change in the strength and stiffness of Viroc CBPB was also examined under various exposure environments, that is, under normal indoor, under free CO_2, under outdoor protected and under weathering exposure. A summary of the results is given in Tables 9 and 10. Examples of the stress and strain are plotted and given in Appendix B.

Table 9 Average change in strength of CBPB under various environments in % of fresh CBPB

Exposure time (month)	CO_2 free	Normal air 20°C/65%rh	Outdoor protected	Weathering
0	0	0	0	0
1	2.26	3.48	x	x
2	-2.54	1.79	9.32	-3.20
4	1.69	16.76	15.82	-6.78
6	5.56	23.35	21.47	-1.13
9	x	26.55	x	7.63
12	x	31.82	x	21.37
18	x	40.21	x	31.64
48	x	42.28	x	34.93

Table 10 Average change in stiffness of CBPB under various environments in % of fresh CBPB

Exposure time (month)	CO_2 free	Normal air 20°C/65%rh	Outdoor protected	Weathering
0	0	0	0	0
1	-18.65	-14.74	x	x
2	8.10	-1.52	-1.32	-6.65
4	10.85	35.45	34.11	16.72
6	13.72	45.99	40.69	20.27
9	x	52.62	x	33.50
12	x	59.22	x	50.25
18	x	70.56	x	80.71
48	x	84.26	x	86.63

Tables 9 and 10 show that the change in the performance of CBPB is closely related to the exposure conditions. A normal air of 20°C/65% relative humidity had most severe effects on both strength and stiffness of CBPB. Free CO_2 air condition had less effect. The different changes under different environments are due to different physical and chemical reactions within CBPB, that is, the effects of moisture content, temperature, contents and quality of surrounding air. In practice, the values under normal air of 20°C/65% relative humidity and out door protected should be viewed as of importance.

It can be seen that the strength of CBPB may increase by about 40% after about 4 years' exposure and the stiffness by about 85%. However, it must be noted that the results are only from 4 test pieces. I strongly recommend that a further test WITH MORE REPLICATES should be carried out should the data be used for an engineering design.

The negative value for the strength change under weathering exposure is may be due to the difference in the moisture content of CBPB.

3 Mass and dimensional change of Viroc CBPB

In original proposal, only dimensional change was considered important. However, from the construction point of view, the self weight of structural components is of importance to construction design. Therefore, this was added into test programme. That is, both mass and dimensional changes of Viroc CBPB under normal constant condition were investigated. A consistent change in dimension is particularly important for designing the joints/structure of components.

Figures 5-7 illustrate the summarised results of changes of CBPB.

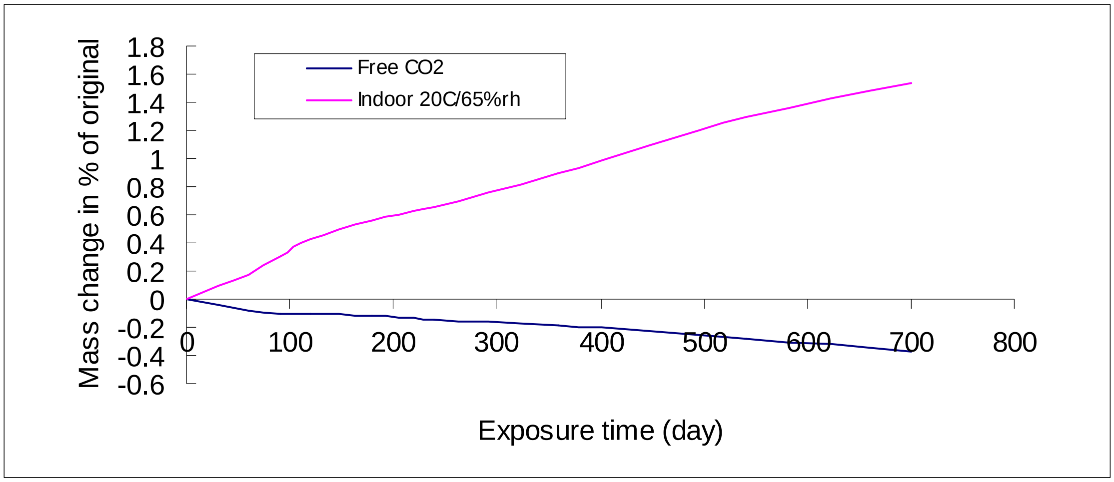

Figure 6 Average increase in mass of Viroc CBPB

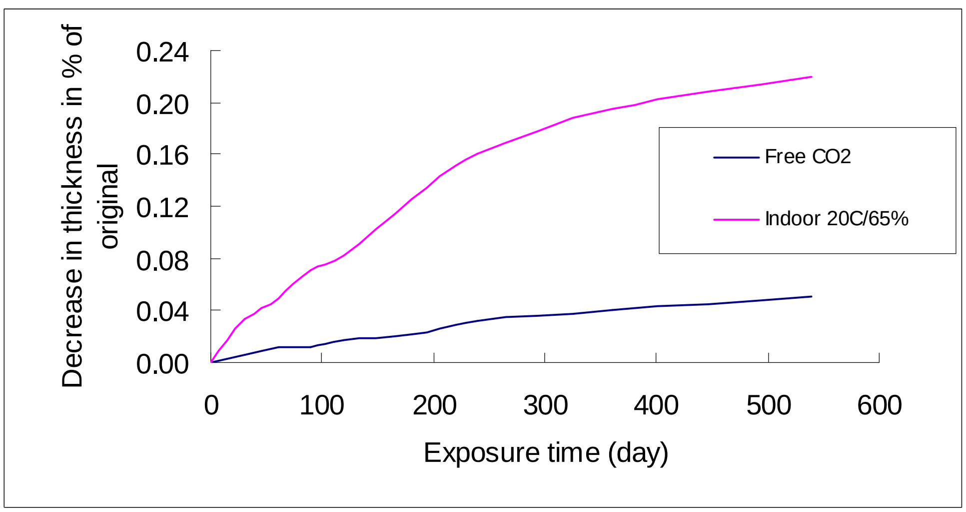

Figure 7 Average decrease in thickness of Viroc CBPB

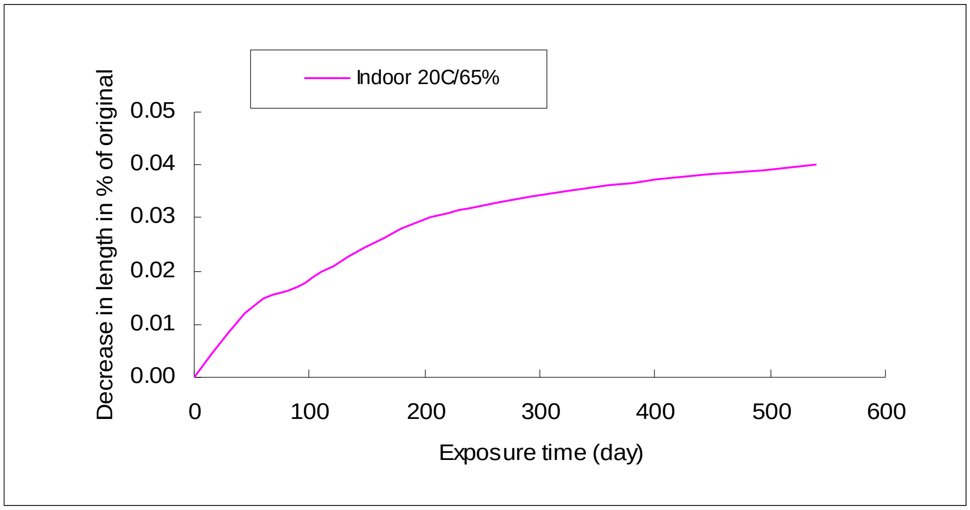

Figure 8 Average decrease in length of Viroc CBPB

In summary, mass of Viroc CBPB consistently increased and dimensions decreased under normal air exposure. It should be NOTED that these changes are irreversible.

This information is particularly important when design construction component by using CBPB.

4 Comparison with EN standards

A comparison of the properties of Viroc CBPB tested with the requirements of EN634-2 is given in Table 11.

Table 11 Main properties of Viroc CBPB compared to those in EN634

	Fresh CBPB	6 month @ 20°C/65%rh	6 months @ weathering	48 months @ weathering	EN634
Density (kg/m^3)	1228	1432	1398	1462	1000
MOR (N/mm^2)	10.62	13.10	10.50	14.33	9.00
MOE ($x1000N/mm^2$)	5.91	8.63	7.11	11.03	4.50

It can be seen that the density of Viroc CBPB is higher than that required. Although this satisfies to the requirements of the EN standard, it is not a favour of design or user. The other important fact is that the density will increase after materials have been installed.

Both MOR and MOE of Viroc fresh CBPB are also much higher than those required:

For fresh Viroc CBPB,

$$MOR_{Viroc} = 1.18 MOR_{S\tan dard}$$

$$MOE_{Viroc} = 1.31 MOE_{S\tan dard}$$

For Viroc CBPB after 6 months' exposure at indoor 20°C/65%

$$MOR_{Viroc} = 1.46 MOR_{S\tan drad}$$

$$MOE_{Viroc} = 1.92 MOE_{S\tan dard}$$

For Viroc CBPB after 6 months' weathering exposure

$$MOR_{Viroc} = 1.17 MOR_{S\tan dard}$$

$$MOE_{Viroc} = 1.58 MOE_{S\tan dard}$$

For Viroc CBPB after 48 months' weathering exposure

$$MOR_{Viroc} = 1.59 MOR_{S\tan dard}$$

$$MOE_{Viroc} = 2.45 MOE_{S\tan dard}$$

It can be seen that there is great potential to design products in factory, such as lower density products, thinner panels or (may be) higher percentage of wood chips; to design components, such as, using different design values rather than the values of fresh panels, lighter components, etc.

Conclusion and recommendations

1. Viroc CBPB tested showed much better performance than those required in EN standards. Moreover, the strength and stiffness of CBPB were consistently increasing with the time of exposure during the testing period of 48 months. This indicated that there are great potentials to design products in the factory, such as lower density products, thinner panels or (may be) higher percentage of wood chips; to design components, such as, using different design values rather than the values of fresh panels, lighter components, etc.

2. Using Viroc CBPB, the following cautions should be taken into account:

- The mass of Viroc CBPB consistently increases,
- The dimension of Viroc CBPB consistently decreases,
- Strength and stiffness of Viroc CBPB consistently increases for at least for the first few years after installation.

3. Environment conditions, where Viroc CBPB are installed/used, should be investigated and taken into account when design. These include:

- Further hydration of Viroc Materials.
- Carbonation of Viroc CBPB.
- Indoor, outdoor, protected or unprotected will have very different effects on the performance of Viroc CBPB.

4. Test data presented in this is from limited number of test pieces, therefore, a further test with more replicates is highly recommended before the data can be used for engineering design.

References

[1] J. M. DINWOODIE, “Wood cement particleboard” (Building Res. Estab. Info. Sheet 2/78, 1978).

[2] J. M. DINWOODIE and B. H. PAXTON, “Inorganic-bonded Wood and Fibre Composite Materials” (University of Idaho, Vol. 1, AA Moslemi, ed. pp115-124, 1988).

[3] M. Z. FAN, J. M. DINWOODIE, P. W. BROWNFIELD and M. C. BREESE, “Inorganic-bonded Wood and Fibre Composite Materials” (University of Idaho, Vol. 5. A. Moslemi, ed. pp103, 1998).

[4] M. Z. FAN, Doctorate thesis, University of Wales, 1997.

[5] M. Z. FAN, J. M. DINWOODIE, P. W. BROWNFIELD and M. C. BREESE, J. Mater. Sci. 34 (1999) 1729.

[6] M. Z. FAN, J. M. DINWOODIE, P. W. BROWNFIELD and M. C. BREESE, Wood and Fibre Sci. (1999) 306-318.

[7] M. Z. FAN, J. M. DINWOODIE, P. W. BROWNFIELD and M. C. BREESE, Cement and Concrete Res. 29 (1999) 923.

[8] EN322, “Determination of moisture content” BSI, London, 1992.

[9] EN323, “Determination of density” BSI, London, 1993.

Appendix A – Physical properties as received

Table A1 MOR, IB and density of CBPB as received

Sample ID	MOR (N/mm^2)	Density (kg/m^3)	IB (N/mm^2)
2	11.20	1355.89	0.92
7	11.00	1364.57	0.87
9	11.33	1443.27	0.78
14	10.41	1272.72	0.93
17	9.86	1257.41	0.90
22	11.01	1349.29	0.87
25	10.48	1345.88	0.71
30	10.98	1445.98	0.73
33	10.65		
38	9.37		
41	10.47		
Mean	10.62	1354.37	0.84
stdev	0.59	68.21	0.08
cov (%)	5.57	5.04	9.98

Table A2 Moisture content of CBPB as received

Sample ID	MC (1 day drying) (%)	MC (1 day + 6 hours drying) (%)	MC (1 day + 72 hours drying) (%)
1	10.69	10.91	11.57
2	10.28	10.28	10.52
3	10.42	10.65	11.12
4	10.75	10.75	11.23
5	10.70	10.70	11.56
6	9.70	9.70	9.95
7	9.93	10.18	10.67
8	10.66	10.66	11.15
Mean	10.39	10.48	10.97
stdev	0.39	0.40	0.55
cov (%)	3.77	3.78	5.05

Appendix B – Examples of stress-strain of CBPB after 4 year weathering exposure

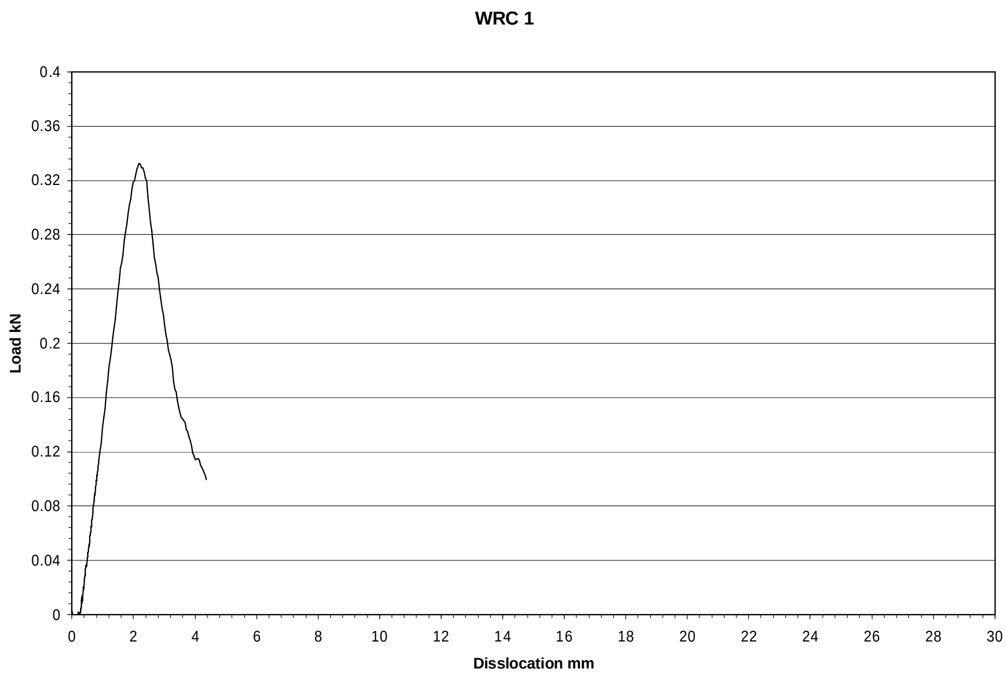

Figure B1 Stress-strain curve of Sample 123: Fmax=332.30N

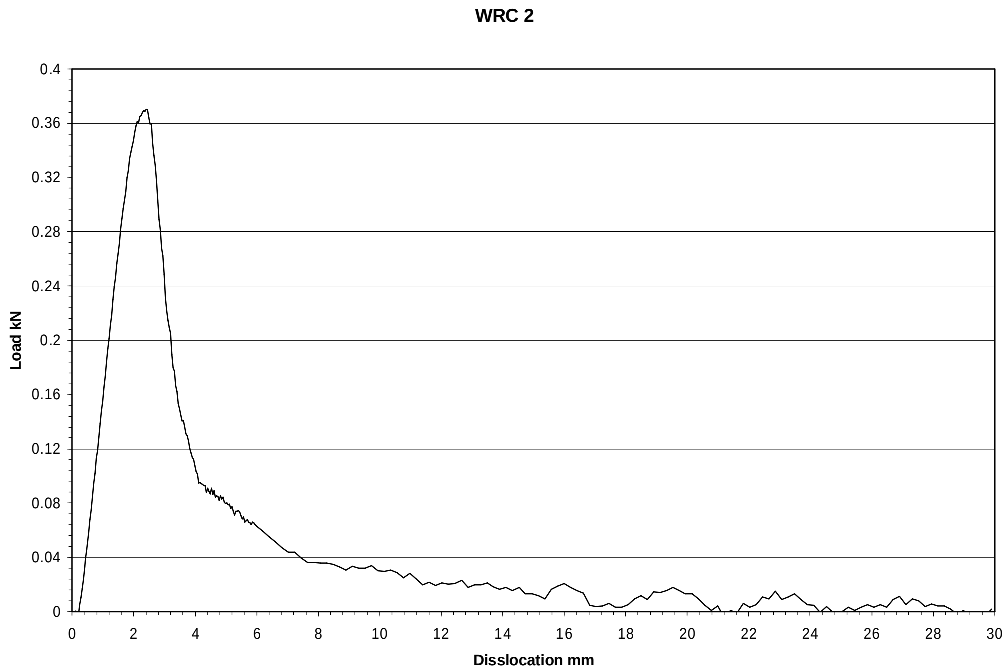

Figure B2 Stress-strain curve of Sample 135: Fmax=370.29N

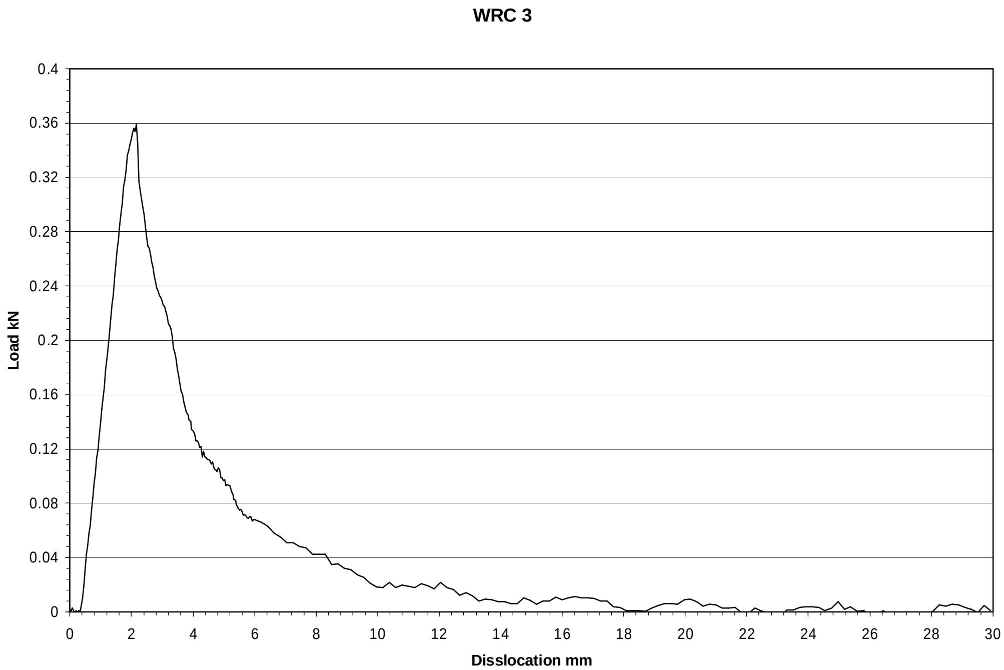

Figure B3 Stress-strain curve of Sample 147: Fmax=358.83N

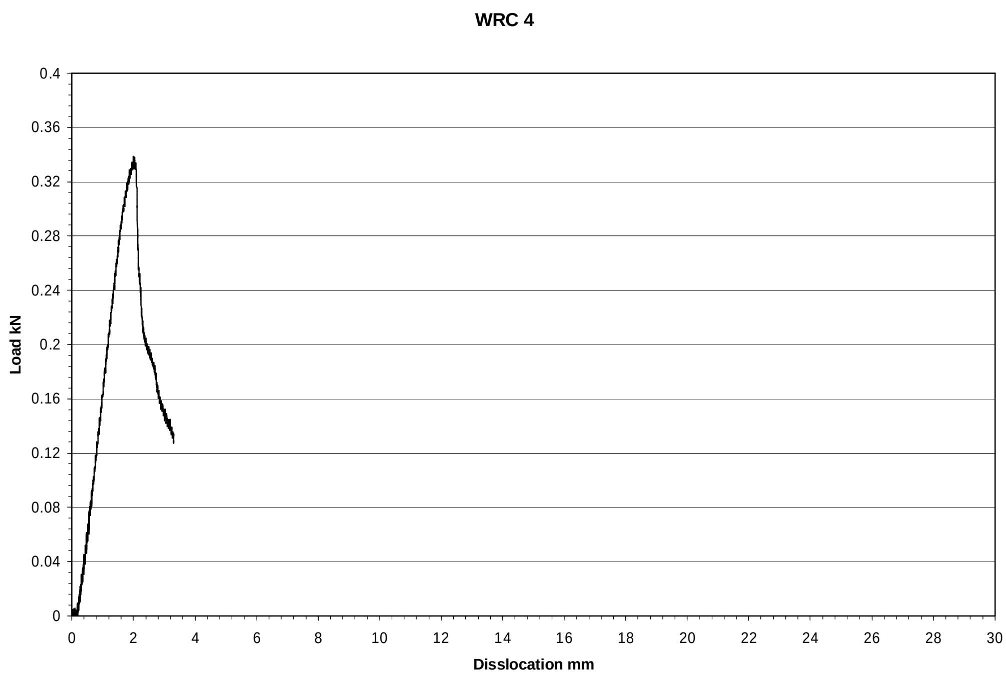

Figure B4 Stress-strain curve of Sample 189: Fmax=338.61N