CARBONATION OF REINFORCED CONCRETE FACADE PANELS - A FIELD INVESTIGATION

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ABSTRACT

Precast sandwich panels constitute a large proportion of exterior wall structures in Finland. Corrosion of the reinforcement is the main factor causing concrete deterioration in exterior structures.

The objective of the research programme described here has been to investigate the present state of the carbonation of concrete facades in Finland and the factors affecting the rate of carbonation.

There was a great deal of variation in carbonation rates at the exterior surfaces studied. Ceramic tiles prevented carbonation, and brick tiles proved to be beneficial, too. Carbonation rates at the inner surfaces of external panels were found to depend on the effectiveness of the ventilation between the thermal insulation and the external panel.

Key words: carbonation, facade panel, reinforced concrete, durability

1. INTRODUCTION

In the early 1960s precast concrete panels were introduced in the construction industry and concrete became a commonly used exterior wall material in Finland. Between 1960 and 1980 the building of blocks of flats was extensive, and a large proportion of facades at that time were built with precast sandwich panels. A typical cross-section of a Finnish precast sandwich panel is shown in Fig. 1.

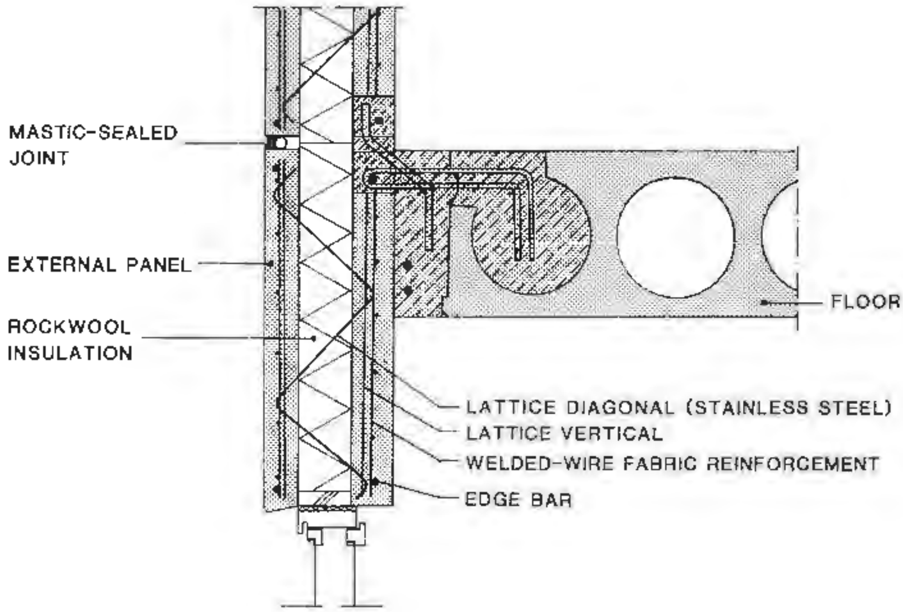

Fig. 1. Cross-section of a precast sandwich panel.

It has become apparent that corrosion of the reinforcement is the main factor causing concrete deterioration in exterior structures. Other factors causing damage in precast concrete panels in Finland are frost attack, the leakage of expansion joint sealants and corrosion of the reinforcement caused by chlorides used as accelerator. The basic causes of durability problems in facade panels are the thinness of the external panel and the poor quality of the concrete. A typical 28-day compressive strength of facade concretes at that time was 20 - 25 MPa. The purpose of this research programme was to determine typical carbonation rates in facade panels and the factors influencing carbonation. The present state of concrete facades and the future need for repairs was to be roughly estimated on the basis of this data. The project was financed by the Technology Development Centre of Finland.

2. EXPERIMENTAL

Most of the examined buildings were local authority blocks of flats in Tampere. The age of the buildings varied between 4 and 29 years. The majority of the buildings were 10 to 20 years old. The number of houses and samples with different finishes (claddings) are listed in Table 1 and the distribution of their ages in Fig. 2. The measurements were carried out in 1988. The figures do not include additional samples for the investigation of the effect of rain exposure.

Table 1. Number of core samples taken from facade panels with different exterior surface finishes.

Surface finish	Number of buildings	Number of samples	Variation of age (years)
Concrete *)	-	15	5.5 - 20.5
Paint	24	115 **)	8.5 - 28.0
Exposed aggregate	6	26	6.0 - 10.5
Ceramic tiles	7	25	10.0 - 22.0
Sand-lime tiles	2	7	5.5 - 26.5
Clay brick tiles	4	15	4.5 - 6.5

*) Samples taken from untreated ground floor panels.
**) Excluding painted samples from the buildings with ceramic tile cladding (9 samples).

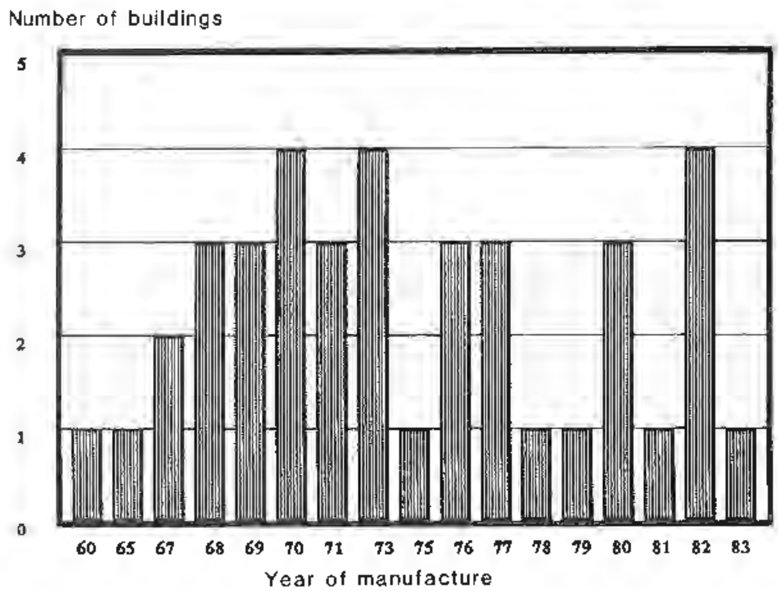

Fig. 2. Year of building of the examined houses.

Five or more samples from the external panels were drilled from every building. The samples were taken in two perpendicular directions and at three different heights (2 to 11 metres from ground level), representing normal rain exposure on facades in Tampere. The field survey included among other things measurements of typical concrete covers of the panels. The samples were then split and the average and maximum carbonation depths at the outer and inner surfaces of the samples were measured with a phenolphthalein indicator. The splitting tensile strengths were tested according to the standard ISO 4108. To determine the influence of rainfall exposure on carbonation some additional samples were taken from panels in both well sheltered and freely exposed parts of the facades.

3. RESULTS AND DISCUSSION

3.1 Exterior surfaces

Variation in the depth of carbonation with age for painted and untreated exterior surfaces is shown in Fig. 3. It can be seen that the results are widely dispersed. Variation in the coefficients of carbonation k calculated from the formula $x = k\sqrt{t}$, where x is the measured average carbonation depth (mm) and t is time (years), is shown in Fig. 4. If we assume that the carbonation progresses according to the square root model, and the covers exceed 25 mm, it follows that most of the investigated panels should reach a service life of over 50 years.

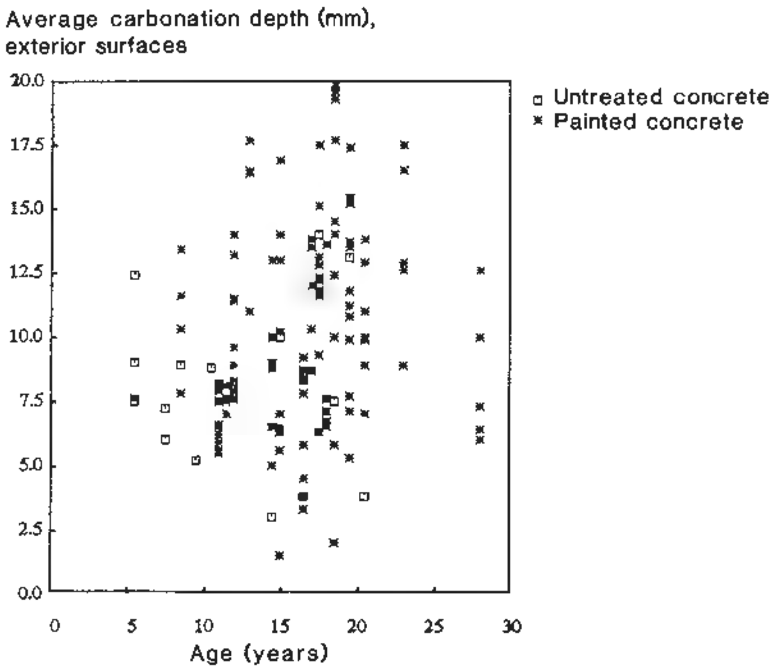

Fig. 3. Measured average carbonation depths plotted against age of panels (painted and untreated exterior surfaces).

There are many variables affecting the rate of carbonation, leading to significant variation in the results. The most important factors are

- quality of concrete, especially the W/C-ratio
- inadequate curing
- possible effects of frost attack
- rain exposure
- surface finish.

Thinness of the exterior panels (typically 60 mm), with poor workmanship and improper inspection, has on the other hand led to inaccurate cover depths of the reinforcement.

As a consequence of both these sources of variations there are going to be buildings, panels and details that will need repairs much earlier than the panels generally.

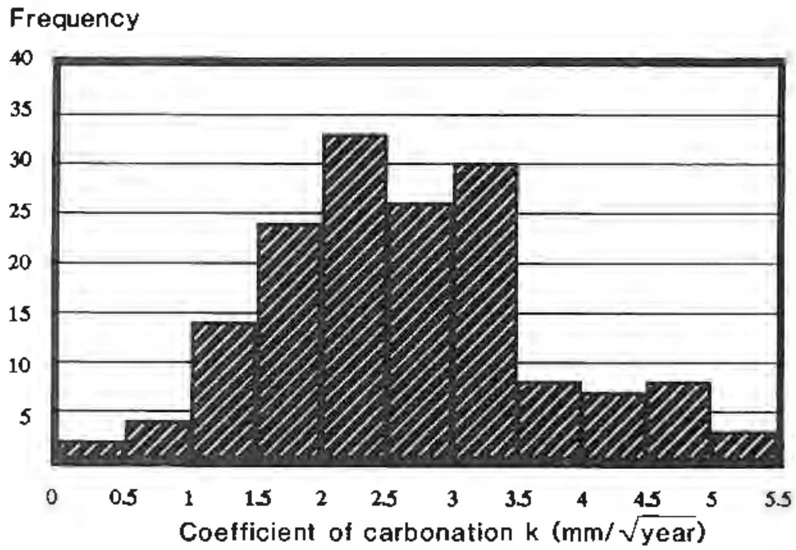

Fig. 4. Distribution of coefficients of carbonation calculated from square root model (painted and untreated exterior surfaces).

The coefficients of carbonation did not correlate significantly to the splitting tensile strengths (Fig. 5).

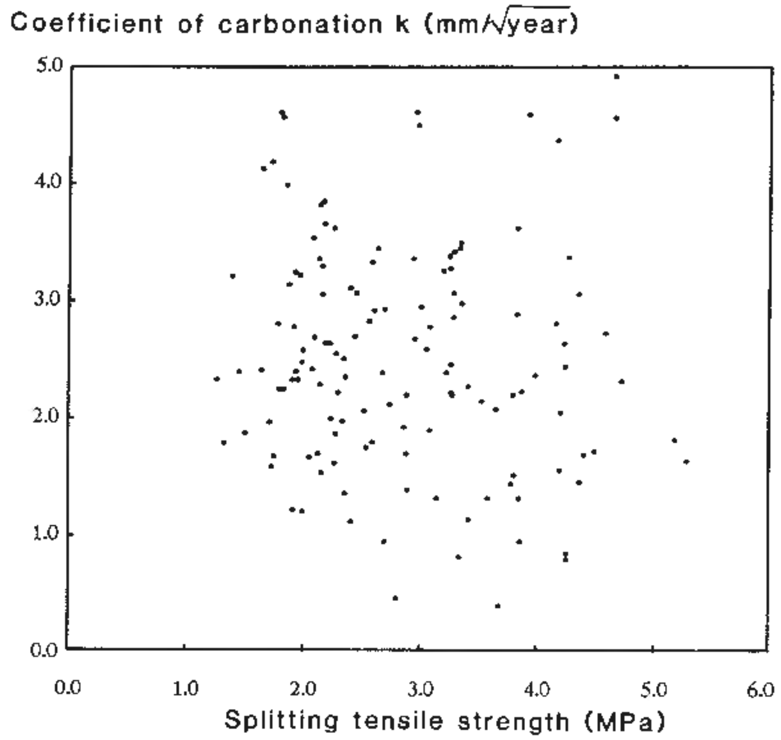

Fig. 5. Coefficients of carbonation plotted against splitting tensile strength.

3.2 Inner surfaces

There is usually no ventilation space between the exterior panel and the thermal insulation (rockwool) in Finnish sandwich structures. However, if the panel has e.g. ceramic tile cladding, the insulation boards are provided with ventilation grooves. The rate of carbonation at the inner surfaces of the exterior panels proved to be lower than on the outer surfaces (Fig. 6). 37 % of the measurements at the inner surfaces showed no evidence of carbonation. The measurements from ventilated structures showed that ventilation accelerates the rate of carbonation compared with non-ventilated structures. Carbonation rates near the ventilation grooves can be as high as on the exterior surfaces of the panels.

The rate of carbonation at the inner surface of the external panel is important because in most cases the reinforcement is located quite near to that surface. The vertical bar of the steel lattice (bearing the dead and wind loads on the external panel) is located nearest to the surface. Corrosion of that bar can therefore weaken the fastening of the external panel.

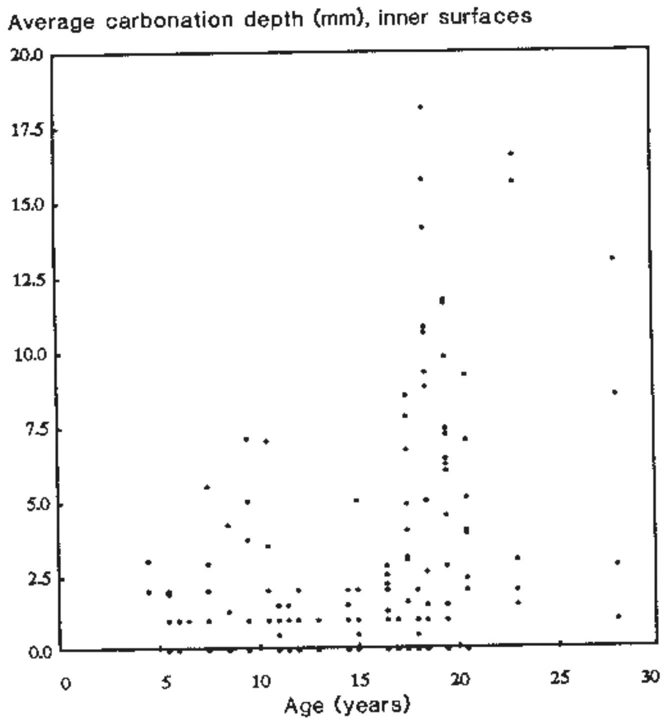

Fig. 6. Measured average carbonation depths plotted against age of panels (**inner surfaces** of external panels).

3.3 Influence of rain exposure

Four buildings were chosen for investigation of the influence of rain exposure on carbonation. Three samples from every building were taken from exposed areas, three from sheltered areas and five from areas having an average exposure. The results are given in Table 2.

The results show, as expected, that the level of rain exposure has an effect on carbonation. The areas where the rain exposure was lowest showed the fastest rate of carbonation.

However, it is usually difficult to take the effect of rain exposure into consideration as the same type of panel can be located in differently exposed areas.

Table 2. Carbonation depths of samples taken from three areas of different rain exposures.

Building no./year of building	Average carbonation depth (mm), exterior surfaces						
	sheltered from rainfall		average rain exposure			unsheltered from rain	
4	23.9	23.6	19.8	19.3	14.5	13.1	9.6
1970	21.4	-	14.0	12.4	-	9.0	
mean	23.0		16.0			10.6	
6	14.9	14.1	17.5	15.1	13.1	13.8	13.7
1971	12.0	-	12.3	11.7	-	12.9	
mean	13.7		13.9			13.5	
17	12.2	11.9	8.1	8.1	7.6	8.5	7.4
1977	10.1	-	7.5	7.0	-	5.2	-
mean	11.4		7.7			7.0	
37	14.1	13.0	13.4	11.6	10.3	9.5	9.4
1980	12.9	-	8.9	7.8	-	8.4	-
mean	13.3		10.4			9.1	

3.4 Influence of surface finish

Ceramic tiles proved effective in preventing carbonation. 25 samples were taken from surfaces with ceramic tile cladding but only two of them had a carbonation depth above zero. The age of the panels varied from 10 to 22 years. The carbonation front was found to penetrate to the concrete-filled joints between the tiles only; there the measured rate of carbonation was slower than on untreated surfaces (Fig. 7).

Although the influence of ceramic tiles is beneficial, the fact remains that panels with tiles have also surfaces without cladding, e.g. at the edges of the panel. The beneficial effect can only be significant if the tiles are not likely to come off.

Clay brick and sand-lime brick tiles appeared to retard the rate of carbonation in the concrete underneath (Table 3).

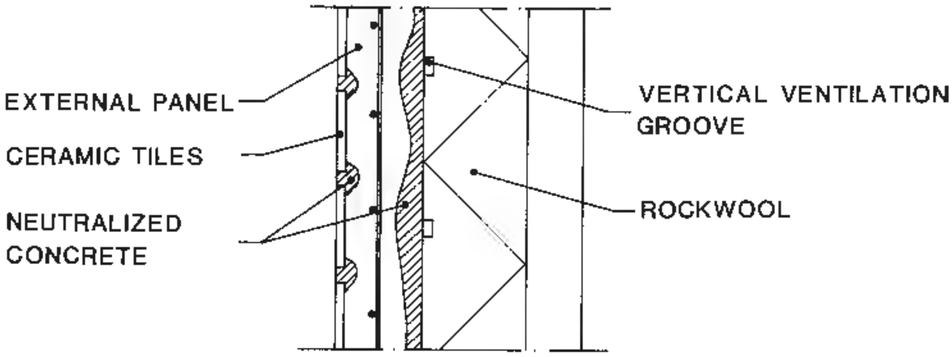

Fig. 7. Carbonation of sandwich panels with ceramic tile cladding.

Table 3. Carbonation depths of panels with brick and sand-lime tile cladding.

Average carbonation depth (mm), exterior surfaces								
Building no.	Age (yr.)	Samples with brick tiles					Samples with concrete surface	
27	6.5	7.0	6.2	5.4	-	-	-	-
29	5.5	3.0	1.6	0.0	-	-	12.4	7.5
31	5.5	0.0	0.0	0.0	0.0	0.0	9.0	-
32	4.5	2.0	2.0	1.5	1.5	-	-	-
		Samples with sand-lime tiles					concrete	
30	5.5	0.0	0.0	0.0	0.0	-	7.6	-
43	26.5	11.1	3.5	2.0	-	-	-	-

Exposed-aggregate finishes showed a faster rate of carbonation than painted and untreated concrete surfaces (Fig. 8). The reason for the faster carbonation rate is probably the greater permeability of the exposed-aggregate concrete, resulting from the mix, the grading of aggregate, the low thickness of the layer in casting and the effect of admixtures and washing treatment.

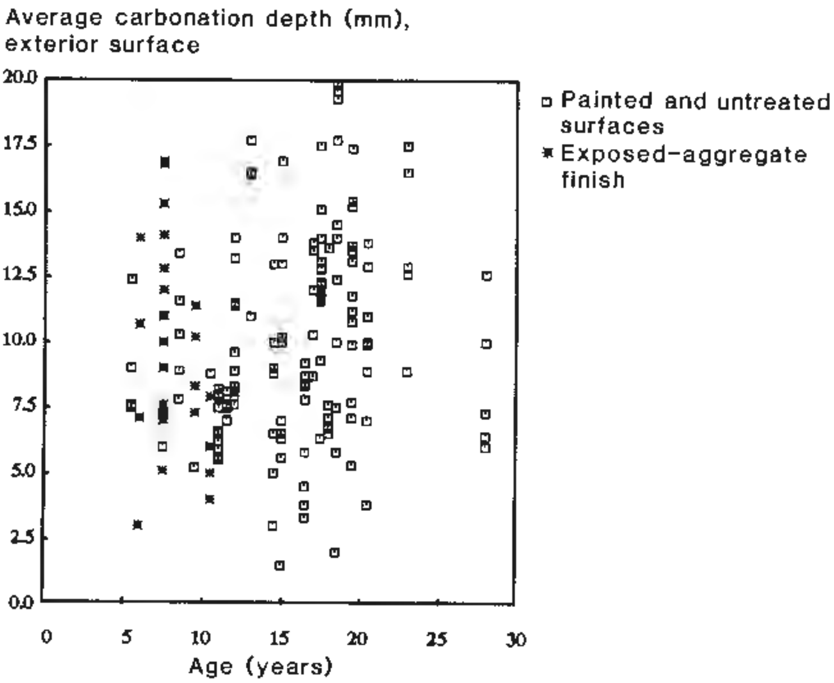

Fig. 8. Carbonation depths of exposed-aggregate finished panels with age compared with painted and untreated samples.

The measured carbonation depths on **painted** facades showed no difference in comparison with untreated finishes (see Fig. 3). A possible reason for the ineffectiveness of organic paints is the water-repellent property of the coat combined with the adequate permeability needed for the evaporation of the excess water.

3.5 Concrete cover on reinforcement

The minimum and maximum covers of reinforcement were measured with a covermeter from two randomly chosen areas of 0.5 m^2 in each building. The results obtained from painted facades are shown in Fig. 9.

The measured thicknesses of concrete cover fulfil quite well the minimum cover requirement of 25 mm set by the official concrete code.

If we compare the measured maximum covers with the thicknesses of the external panels (Fig. 10), it can be seen that the reinforcing bars (especially at the edges of the panels and the vertical bar of the supporting lattice) can be very close to the inner surface of the panel.

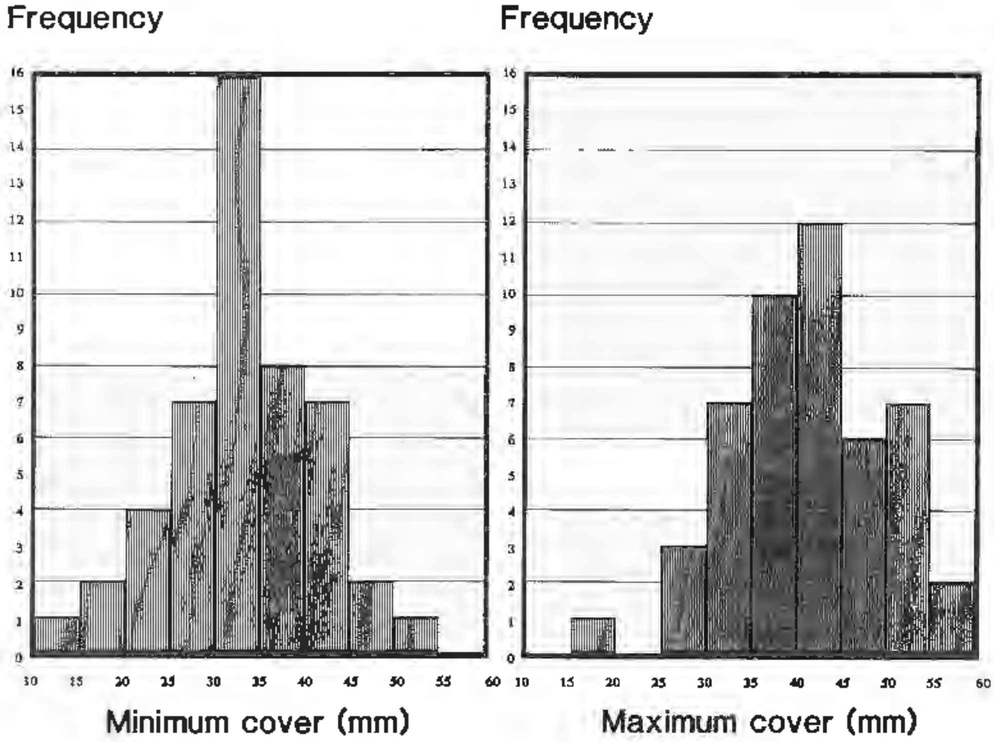

Fig. 9. Distributions of measured minimum and maximum cover.

The covers of reinforcement in panels with tile cladding were found to be thinner than in painted panels; this is caused by the direction of the panels in casting.

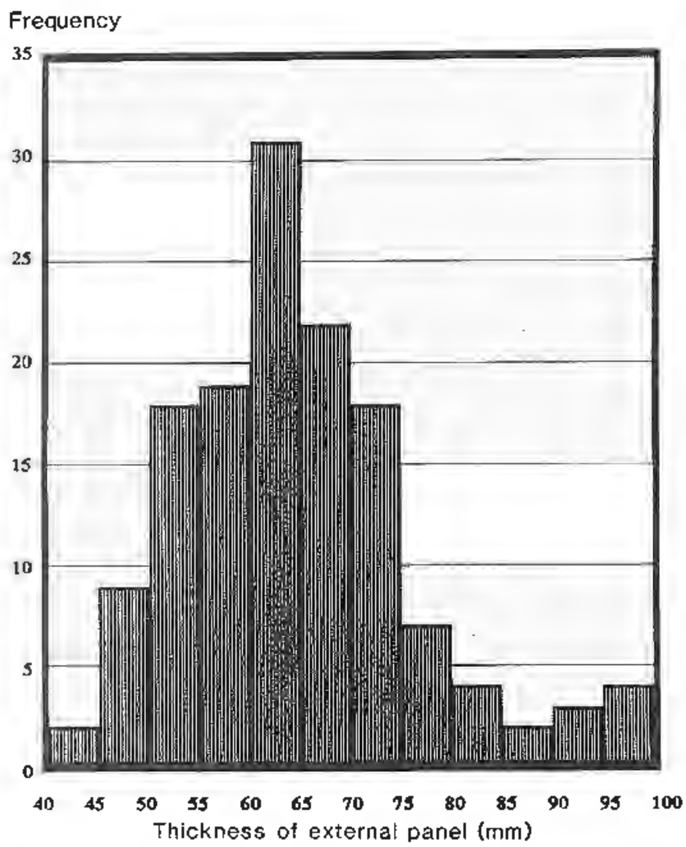

Fig. 10. Distribution of measured thicknesses of external panels.

4. CONCLUSIONS

The main conclusions derived from this investigation are as follows.

1) Variation in carbonation rates is wide and it is therefore difficult to give mathematical models to predict carbonation. Assuming that carbonation follows the square root model, the coefficients of carbonation calculated from these measurements were typically between 1.5 and 3.5 mm/√year.

2) Carbonation at the inner surfaces of external panels has to be taken into account in their design and manufacture, especially in ventilated structures.

3) The benefit from a slower carbonation rate of panels that are freely exposed to rainfall is difficult to consider in design because the same type of panel can be used in areas with different rain exposure.

4) Of different surface finishes, ceramic tiles are the best in slowing the rate of carbonation. However, panels with ceramic tiles are ventilated and often have surfaces without tile cladding, so it is often advisable to use normal cover thicknesses.

5) To ensure an adequate cover on the reinforcement in panel structures, the allowed tolerance in the placing of the reinforcement should be added to the nominal cover (based on service life requirements).

5. REFERENCE

Mehto, L., Pentti, M., Käkönen, H., Carbonation of Conrete Facades (in Finnish). Tampere University of Technology, Structural Engineering, Report 41. Tampere 1990.