THE PERFORMANCE OF POLYMER IMPREGNATED CONCRETE BEAMS AFTER 19 YEARS OF OUTDOOR EXPOSURE

H. Justnes, Research Engineer (PhD),
The Cement and Concrete Research Institute at the Foundation for Scientific and Industrial Research, N-7034 Trondheim, NORWAY

B. Søpler, Ass. Director (MSc),
Norcem A/S,
Concrete Technology Research,
N-3950 Brevik, NORWAY

ABSTRACT

The weathering resistance of polymer impregnated (PIC) concrete beams after 19 years outdoor exposure has been evaluated by comparing the load capacity with the original values. In addition, visual inspection and measurement of carbonation depth were carried out. The results revealed that the tested beams are in good mechanical condition, but the PIC based on the lowest concrete quality (C20) had lost some load capacity. The concrete had maintained its alkalinity. However, some moss had grown on the surface.

Key-words: Polymer Impregnated Concrete, PIC, Weathering, Flexural Strength

1. INTRODUCTION

Polymer Impregnated Concrete (PIC) is defined as "a hydrated Portland cement concrete which has been impregnated with a monomer and is subsequently polymerized *in situ*". PIC can be fully or partially impregnated.

According to a recent review by Fowler /1/, full impregnation requires the concrete to first be dried at 120 to 150°C, cooled, evacuated in a vacuum chamber, soaked in monomer under pressure, and placed in a hot water bath or steam chamber for curing. There have been numerous applications investigated to utilize the excellent mechanical and durability properties of fully impregnated PIC, but there are no known commercial applications. The high initial cost of a process facility is probably the greatest deterrent to the further development of PIC products. Among others, measures must be taken to limit the explosion risk and potential health hazard when volatile monomers are used.

Partial impregnation was originally developed for the treatment of highway bridge decks to improve their resistance to freeze-thaw deterioration and chloride intrusion. The process requires the concrete to be dried at a surface temperature of approximately

120°C for 5 to 8 hours, cooled, soaked with monomer (e.g. MMA) for 4 to 6 hours using a 1 cm thick sand cover, and polymerized using low pressure steam or warm forced air. Impregnated depths of 15 to 35 mm can be achieved. Parking garage floors, outlet walls in a dam, the floor of a stilling basin, and the badly deteriorated concrete ceiling of a jail have been successfully treated in USA.

Polymer impregnation of bridge decks received considerably emphasis from 1970 to 1978. However, there was concern that chlorides could penetrate through the shallow impregnated zone by means of very fine cracks that result from drying the concrete or curing the monomer. Polymer impregnation is not used at present in USA /1/; the last major application was the impregnation of the road way of the Grand Coulee Dam at a cost of \$51 m^2 in 1982 /2/.

In spite of the lack of current commercial activity, several potential applications exist. Post-tensioned PIC beams and girders used in corrosive environments such as bridges in coastal areas offer the combination of high strength, low creep, and excellent durability. PIC beams have been shown to be capable of carrying up to 3 times more load compared to the same size unimpregnated section. The low creep of PIC (less than 10 % of normal concrete) results in less loss of prestress /3/.

The only world-wide example of commercial production of polymer impregnated concrete precast products are Chichibu Cement, Ozawa Concrete Industries and Taisei Corporation, Japan /4/. In addition, experimental production of radioactive waste containers, interlocking blocks, permanent forms etc has taken place in Japan.

In the periode 1969-1973 /5-7/ experiments with polymer impregnation of precast concrete details were performed at the Cement and Concrete Reseach Institute, Norway. Polymer impregnated curbstones were in 1971 set out at Økern cross road, Oslo, Norway, in cooperation with Oslo Road Minestry. The PIC specimens were compared with untreated curbstones, and the performance of the curbstones was followed for 8 years. The general results are presented in Fig. 1.

The curbstones characterized in this study were put on the roof top of the Cement and Concrete Research Institute, Trondheim, September 1971 and taken down in May 1990 for inspection and testing.

2. EXPERIMENTAL

All curbstones were made from the same cement (Nordland Portland Cement Fabrikk) and aggregate, d_{max} = 15 mm (Sandkompaniet, Trondheim), in three different concrete qualities; C20 (w/c = 0.8), C40 (w/c = 0.56) and C60 (w/c = 0.4). All mixes had a consistancy corresponding to a slump of 7-8 cm. The curbstones were stripped from the molds after 1 day (2 days for the C20-serie) and cured immersed in water until 7 days age. They were then dried for 7 days at 105°C prior to the impregnation. The curbstones were submersed in methylmethacrylate (MMA) monomer with 3 % bensoyl peroxide (BPO) for 18 hours as an impregnation. The polymerization process was triggered by submersing the samples in water at 70°C for 4 hours. The length of the curbstones was 95 cm, and for the load capacity testing the point load was put in the middle of the 90 cm span (see Fig. 2).

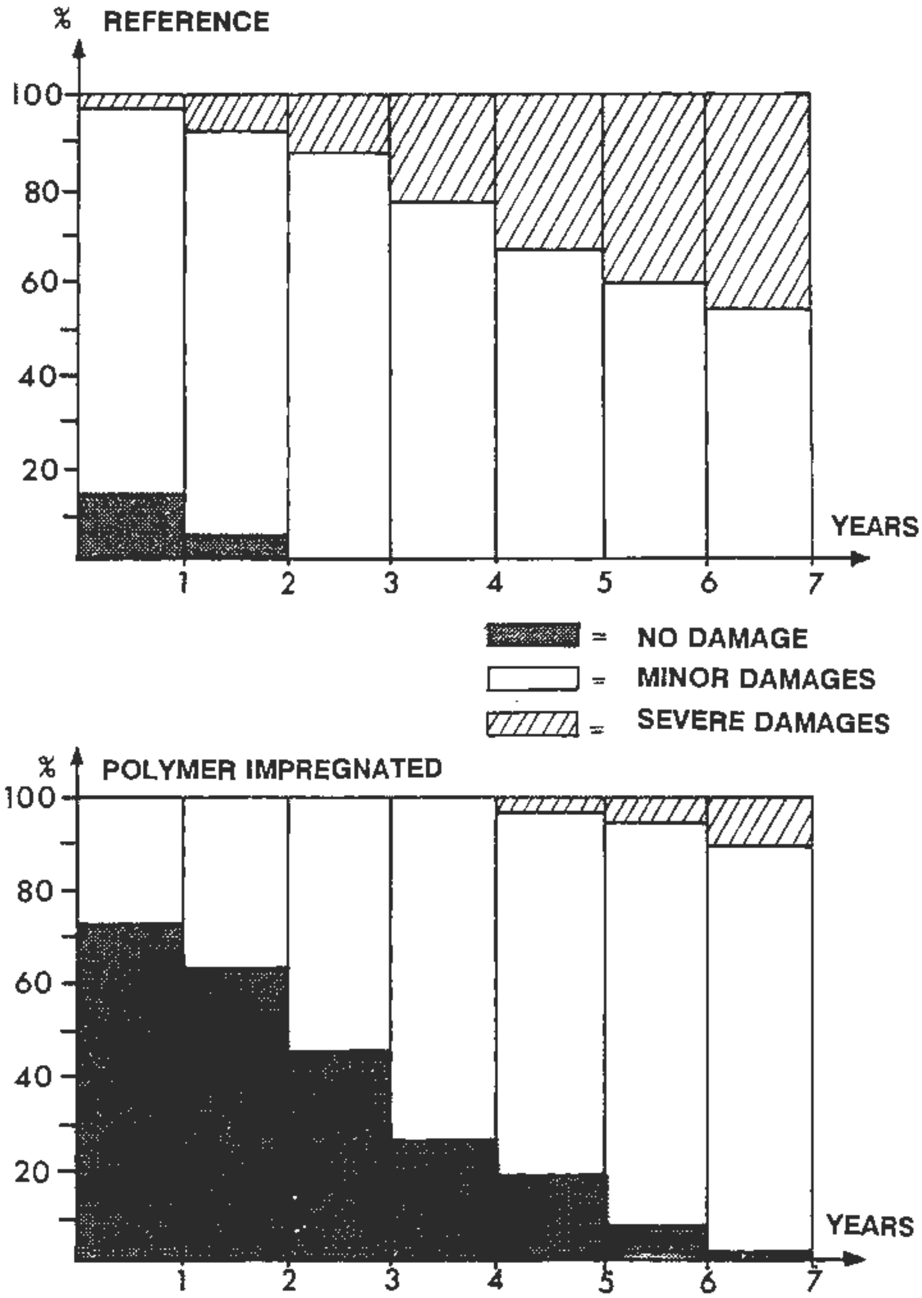

Fig. 1 An evaluation of the performance of untreated concrete curbstones (upper figure) and PIC curbstones (lower figure) during 7 years of field exposure with heavy traffic.

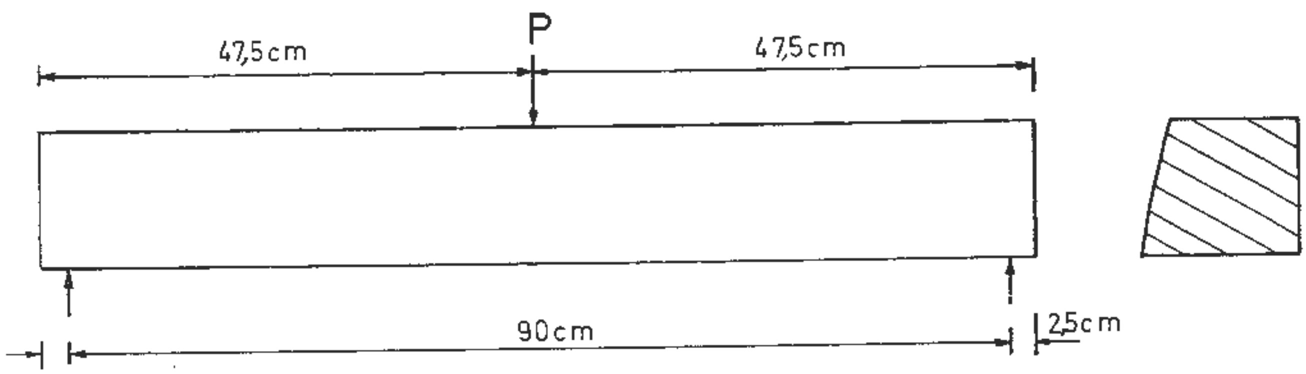

Fig. 2. Dimensions of the curbstones and set up for the testing of load capacity.

3. RESULTS

The curbstones taken from the roof top after 19 years outdoor exposure were marked A26, A27 (C20 quality), B28 (C40) and C26 (C60). An overview of the curbstones is shown in Fig. 3. The weight changes for the curbstones are given in Table 1.

Table 1. The weight change for curbstones during treatment and exposure.

No.	$mass_w$ (kg)	$mass_d$ (%)	$mass_p$ (%)	$mass_e$ (%)	$mass_t$ (%)
A26	38.210	-6.83	-1.47	-2.28(?)	-1.47
A27	38.090	-6.93	-1.47	-1.55	-1.42
B28	38.590	-5.80	-1.24	-1.53	-1.40
C26	38.340	-6.47	-1.46	-1.54	-1.41

Subscript characters for the masses: w = wet, d = dry, p = after polymerization, e = when put on the roof top, t = when tested

The results from the load capacity testing of concrete and PIC curbstones at 28 days age are compared with the strength of PIC curbstones after 19 years outdoor weathering in Table 2.

A close up of the fractured surfaces of the curbstones after the load capacity experiments is shown in Fig. 4, revealing the impregnation depths (grey layer). Phenolphtalein indicator sprayed at all the fracture surfaces turned pink, prooving that the alkalinity of the concrete was maintained for all the samples.

Table 2. Load capacity of curbstones after 28 days curing and 19 years weathering.

Quality	Treatment	Failure load
C20	28 d, OC[1]	6,100 N
C20	28 d, PIC	26,500 N
C20	19 yr, PIC	17,700 N
C40	28 d, OC	8,700 N
C40	28 d, PIC	21,500 N
C40	19 yr, PIC	21,200 N
C60	28 d, OC	11,700 N
C60	28 d, PIC	23,500 N
C60	19 yr, PIC	19,400 N

[1]OC = ordinary concrete (not polymer impregnated)

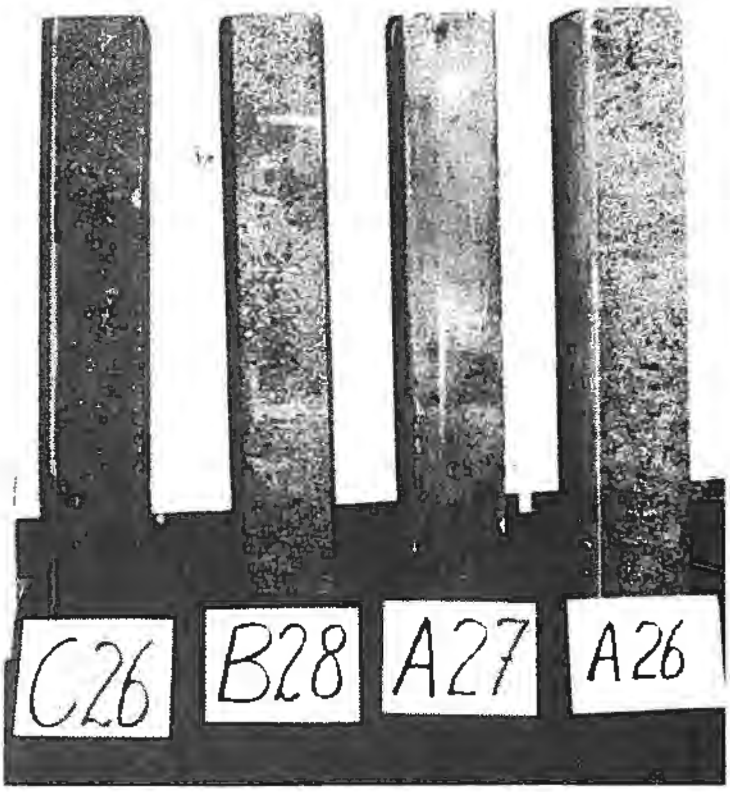

Fig. 3 An overview of curbstones after 19 years outdoor weathering

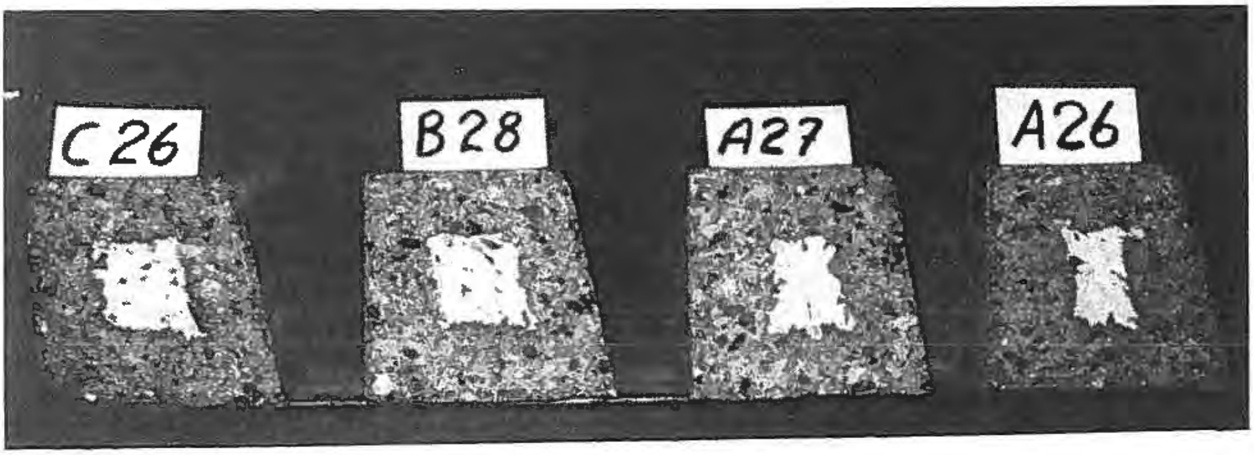

Fig. 4. A close up of the fracture surface of the curbstones after the load capacity experiment.

4. DISCUSSION

The damage evaluation of curbstones shown in Fig. 1 is based on a great number made of both ordinary concrete (OC) and polymer impregnated concrete (PIC). For the 7 years periode, there is no doubt that PIC curbstones have a better durability towards both freeze-thaw action and abrasion by traffic.

However, in the evaluation of the 19 years old curbstones exposed to outdoor weathering, there exist only two parallels of the C20-based PIC, and one specimen of the two other qualities. Hence, the conclusions drawn in this discussion are not necessarily representative.

The results in Table 1, indicate that the polymer loading during the impregnation process for curbstone A26, A27 (C20), B28 (C40) and C26 (C60) is 5.4, 5.5, 4.5 and 5.0 %, respectively. The reason why the C40-quality is less impregnated than the C60, even though the fraction of capillary pores should be greater, is probably due to unsufficient drying (less weight loss). The weight of the curbstones seems to be unchanged compared with the weight after polymerization, indicating a stable product.

Table 2 reveals that the load capacity of the curbstones of quality C20, C40 and C60 increased with 334, 147 and 101 %, respectively, after the impregnation process. However, the PIC curbstones based on concrete with quality C20, C40 and C60 lost 33, 1 and 17 %, respectively, of its load capacity during the 19 year outdoor exposure. The tendency of increasing strength loss with increasing drying loss might be a coincidence, but the relation is quit linear (see Fig. 5). If significant, the explanation for the relation might be microcracking during drying.

The reason for strength loss may be freeze-thaw action, with freezable water entering through microcracks. The climate winter-time in Trondheim is shifting from usually +5°C (max +10°C) to -10°C (min -20°C), with a capacity of quite a number of cycles (approx. 50) each year, and a lot of precipitation either as rain or snow. Thus, the curbstones might have gone through several 100 freeze-thaw cycles during the 19 years of outdoor exposure.

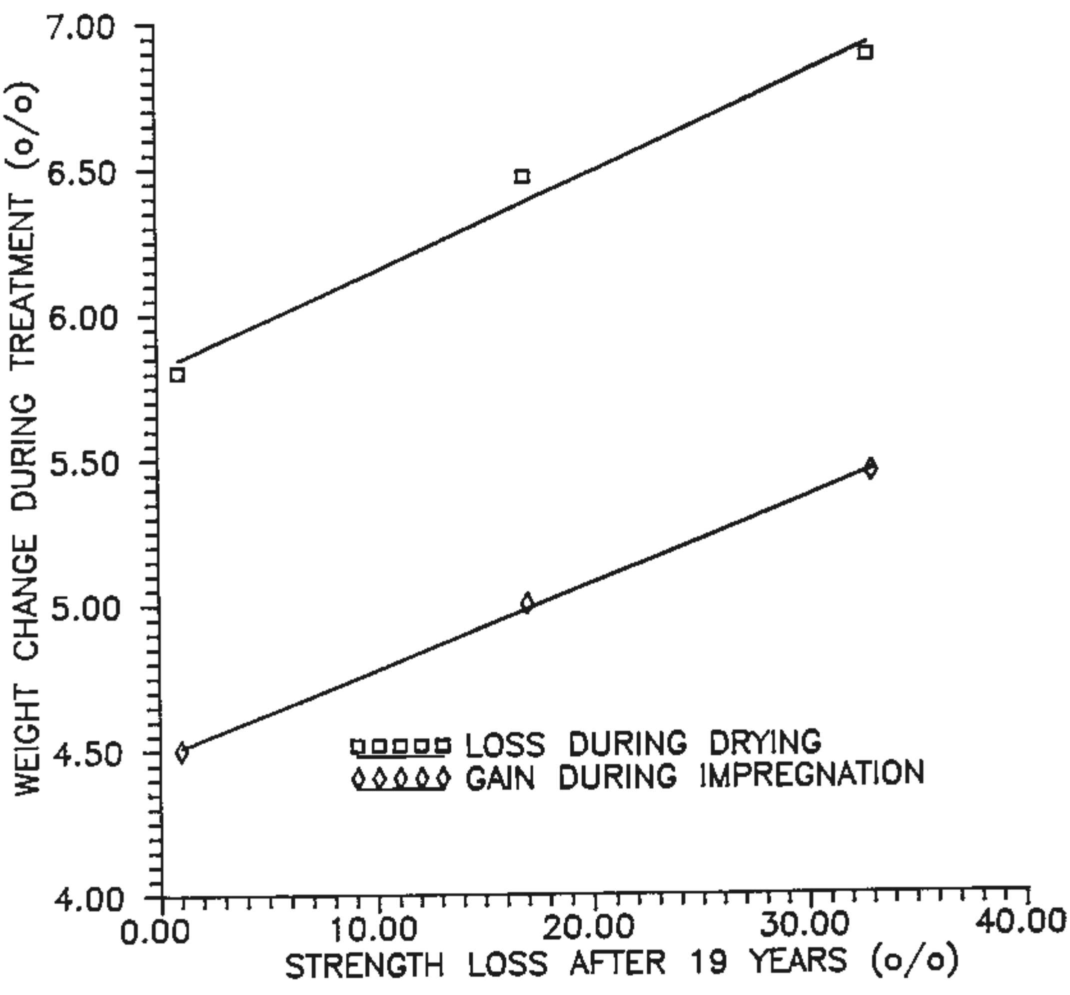

Fig. 5. The linear relation between weight loss during drying and polymer loading with strength loss of PIC curbstones during 19 years outdoor weathering.

5. CONCLUSION

The polymer impregnation of concrete (PIC) curbstones seems to enhance both strength and durability. The PIC curbstones had still a triple load capacity compared with the original reference concrete after 19 years outdoor weathering, although some strength loss was noted compared with the original PIC curbstones. The latter strength loss, ranging from 33 to 1 %, is attributed to freeze-thaw action, although no spalling was observed. The polymer (MMA) impregnation gave apparently a good protection against carbonation.

6. REFERENCES

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