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Thaumasite sulphate attack at the concrete structures of the Ferenc Puskás stadium in Budapest

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Abstract

After World War II, in order to minimise the significant cement deficiency (caused by the demand of restoration works and prestigious capital investments of the governing regime) a clinker saving cement mix named 'Sigma Cement' was produced in Hungary. The patent lay in replacing the coarse clinker particles with limestone powder. Under the effect of waste gases from the nearby railway station and rubber plant the structural concrete of the largest Hungarian Sports Stadium suffered significant damages due to carbonisation and sulphating in which thaumasite sulphate attack may have played its role.

Keywords: Beton corrosion; Limestone; Composite cement; Sulphate attack

1. Background

There is no doubt that of the giant maniac constructions of the post-World War II regime the so called People's Stadium was the most popular one since the Hungarian nation, always proud of its sports successes, had always longed for a sports establishment capable of holding many people. It was characteristic of the public mood of those times that the first democratically elected Parliament approved the construction costs already in 1945 when most of Budapest still was lying in ruins. Arguments for the construction of a new stadium were supported by the fact that in 1947 the overloaded wooden structure grandstand of the largest stadium collapsed during a class A football match.

Soon after the accident the construction was started according to the design of Dávid and the inauguration ceremony took place in August 1953. For the construction of this ever largest Hungarian reinforced concrete structure 60,000 m^3 of sandy gravel, 14,000 ton of cement and 2500 ton of reinforcing bars were used [1–3], (Fig. 1).

The establishment accommodating 70,000 spectators witnessed numerous outstanding sports successes (e.g. in 1954 the football match Hungary–England which ended with the result 7–1 and in which played Ferenc Puskás, after whom the stadium has been named. He scored two goals).

The history of the reinforced concrete structure of the stadium, however, proved to be less successful. From the mid-sixties, the strength of the concrete started to gradually and significantly decrease, which is shown in the following figures (Figs. 2–4).

In the following we will overview some details of the story related to the chemistry of cement.

2. Materials used for concrete preparation

During the period of construction the builders had to permanently face an extraordinary deficit of materials. For example, no classified aggregate was available and the reinforcing steel had to occasionally be procured from as far as Pakistan (!). Most depressing, however, was the deficiency of cement.

2.1. The 'Sigma Cement'

Upon the recommendation of S. Gottlieb, a cement specialist who had returned from emigration after the war, for the preparation of structural concrete the clinker saving cement type 'Sigma Cement' patented by the very same man was used [4–6]. This cement is said to have been successfully produced in the Haifa cement plant during the war. The patent essentially lies in the

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Fig. 1. Ferenc Puskás Stadium in Budapest.

Fig. 2. A typical damage of the concrete—1.

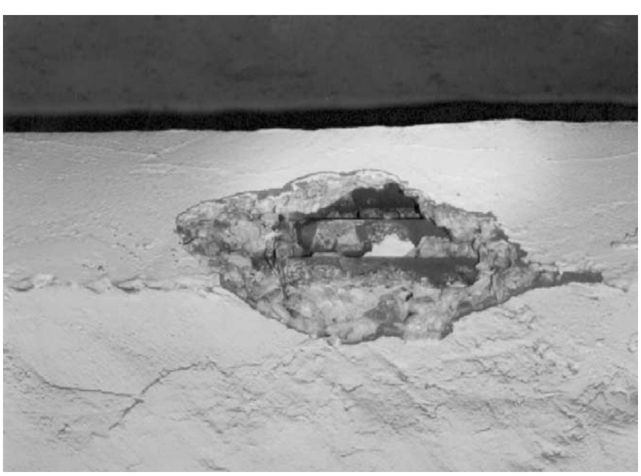

Fig. 3. A typical damage of the concrete—2.

separation of the coarse fraction of the cement clinker (particle size >60 μm) not participating (?) in the hydration and its replacement by powdered porous limestone. Thereby the strength of the cement allegedly would not decrease while the water absorbed by the porous limestone would prevent the concrete from drying out. (We note that in those times no separators allowing adequately fine separation were available in the Hungarian cement industry. Moreover, we are afraid there may not be such ones even today.)

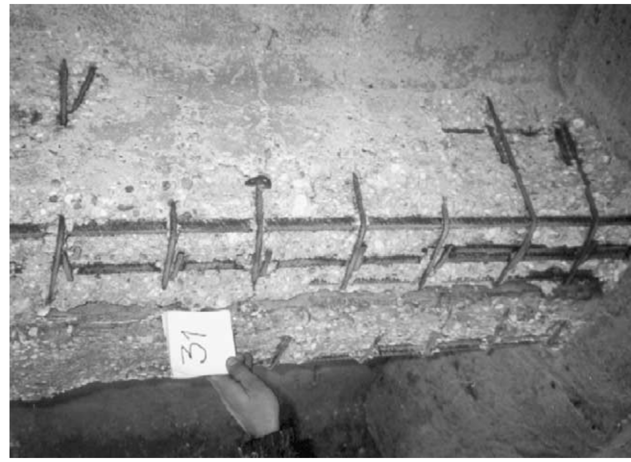

Fig. 4. A typical damage of the concrete—3.

This cement was produced in the Lábatlan Cement Plant, 50 kms North-West of Budapest. We undertake a difficult task when trying to characterise the properties of that cement. What is certain is that the raw material base of the plant has remained unchanged (Table 1) and powdered coal firing is still applied there. We also found data on the composition of the clinker used at that time. As an additive to cement, instead of the dense limestone (originating from the Triassic period) of the plant's own quarry, a much more contaminated soft Eocene limestone from a nearby quarry was used (Table 1, column e). The planned limestone content of the cement amounted to 15%. Cement was prepared in 3-chamber ball mills through simultaneous grinding of the components. Its specific surface may have been around 2800–3000 cm^2/g

Table 1
Compositions of raw materials, raw mix and clinker

Chemical analyses; Labatlan cement work					
	Limestone	Marl	Correction component	Sand	Clinker
LOI	43.23	24.29	4.97	8.04	0.25
SiO_2	1.42	30.19	12.27	70.91	20.81
Al_2O_3	0.13	8.33	2.23	5.76	6.02
Fe_2O_3	0.12	4.77	67.79	3.12	4.16
CaO	54.27	28.17	5.82	7.86	2.68
MgO	0.79	3.15	3.41	1.54	0.44
SO_3	0.52	0.63	3.51	0.21	0.44
CO_2	43.01	21.06	–	–	
Free CaO					0.98
Lime saturation					94.14

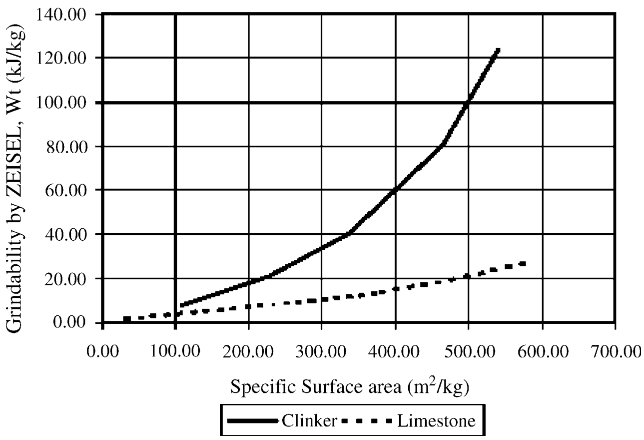

Fig. 5. The examination of the grindability of the clinker and the Eocene limestone with Ziesel method.

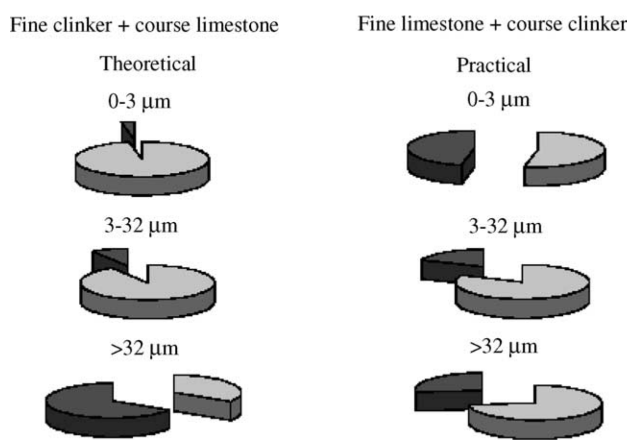

Fig. 6. Individual dispersions of the components in the cement. *A* planned, *B* most probable value.

according to Blaine. We carried out grind ability tests according to Zeisel and simulative laboratory grinding experiments in order to make conclusions on the possible individual dispersity of the components. Based on these tests and experiments it may be supposed that the more easily grindable limestone accumulated—contrary to the inventor's intentions—not in the coarse but in the fine fractions of the cement (Figs. 5 and 6). As to the other properties of the cement no more data are available.

3. Concrete preparation

Reinforced concrete structural elements of the establishment were prepared by the on-site prefabrication method. Concrete quality may have been equal to C 20 according to the current terminology [7]. For the preparation of the concrete mix unclassified sandy gravel up to 30 mm aggregate size was used. The nominal cement

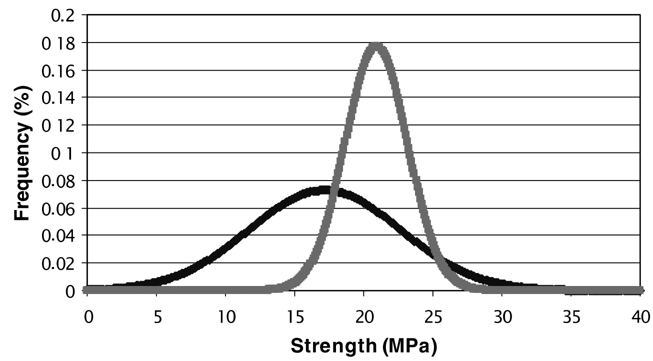

Fig. 7. Twenty eight-day strength of the concrete.

content amounted to 270 kg/m^3, water was added to achieve a slightly plastic consistency. The strength of the concrete was regularly tested ($20\times20\times20$ cm cube specimens). Twenty eight-day strength values are shown in Fig. 7. For comparison purposes strength data are shown also for a concrete prepared at the same time with a cement from another plant the quality of which corresponded to class CEM I 32.5 according to the current terminology. The poorer quality of the concrete made with the Sigma Cement is obvious.

4. Environmental effects

At the time of the construction and even some 20 years after it the surroundings of the stadium belonged to the district of the town with the most polluted air because of the nearby rubber plant and the railway station with coal-fired steam-locomotives next to the stadium. The corrosion that took place under the simultaneous effect of the air polluted with carbon dioxide and sulphur oxides together with the rainwater [8] had also been pointed out already in an earlier expert's report [9]. The average temperature in Hungary is about 70% of the year longer than 15 °C which is advantageous for thaumasite formation.

5. Concrete strength deterioration

According to the results of Schmidt-hammer tests regularly carried out since 1973 the strength of the concrete has been gradually decreasing with an ever-growing deviation (Fig. 8). Therefore in the nineties significant restoration works took place and simultaneously various safety measures were taken such as limiting the number of spectators or banning high-load beat concerts. And, finally, in the year 2000 a decision was made on the complete demolition and the construction of a new stadium on the same spot.

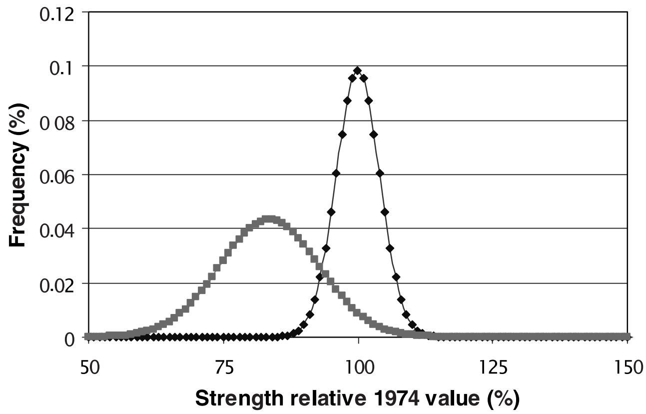

Fig. 8. Average strength and its deviation for the concrete as measured with Schmidt hammer in 1964 and 1973.

6. Corrosion processes in the concrete

Unfortunately only in 1996, that is much later than the first unfavourable phenomena had been observed, could we execute tests of chemical character that allowed to make more exact conclusions concerning the reasons of deterioration.

These investigations included:

- bulk density of the concrete;
- cement content of the concrete;
- limestone content of the cement used;
- chemical characteristics of the cement stone (carbonation, sulphating, pH).

For the determination of these properties partly traditional [11–13], partly XRA and thermal analytical methods were applied [10]. A methodically interesting part of the investigations was the parallel determination of the two types of calcium carbonates and calcium sulphates: that is the primary compounds originally existing in the cement and the secondary ones developing in the course of the corrosion process. The essential test results and calculation data are summarised in Table 2.

From their analysis the following conclusions can be made:

Table 2
Chemical properties of the concrete

	Average	Minimum	Maximum	Deviation
Density (kg/m^3)	2124	1830	2380	234
Cement content (kg/m^3)	215	95	560	111
Limestone in the cement (%)	27.6	22	39	7.1
pH	9.5	7	12	2.1
Carbonatization (%)	15.45	9.8	19.7	3.85
Sulfatization (%)	1.46	0	2.45	0.81

- the average bulk density of the concrete is low while a considerable scattering of the results can be observed;
- the average value of the cement content is correct but with high scattering;
- the limestone content of the cement varies between wide limits while the average value one and a half times exceeds the nominal one;
- the pH index of the concrete varies between 7 (!) and 12;
- the active CaO content of the cement stone is significantly sulphated and carbonised.

Finally we show a characteristic derivatogram [14] and XRD curve. The derivatogram was made in 1995,

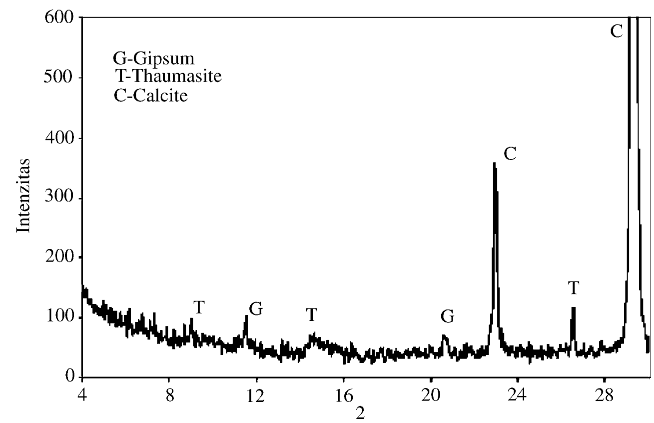

Fig. 9. XRD curves of the concrete in 2001.

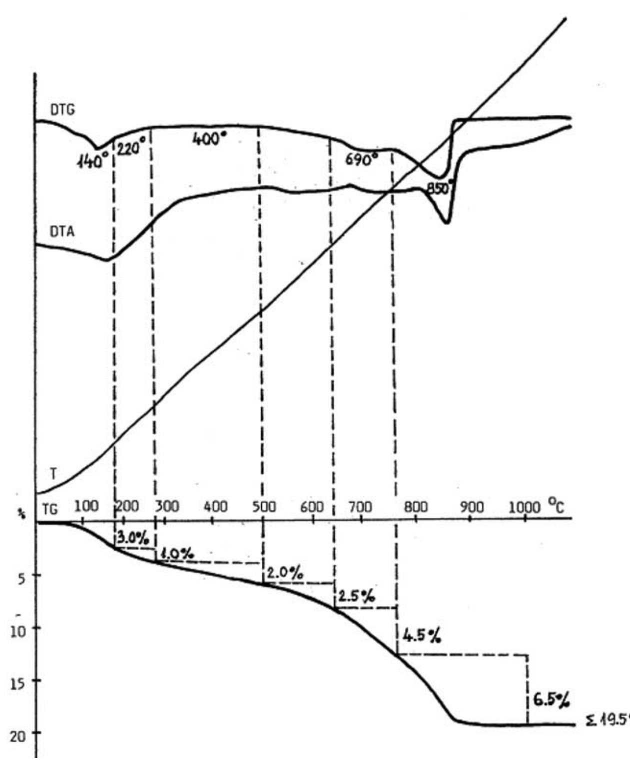

Fig. 10. Derivatogram of the concrete in 1995.

while some examinations we carried out on samples taken at the end of the past year (Figs. 9 and 10). In the derivatogram the peaks of the primary and secondary phases can rather easily be distinguished.

In the XRD ($2\Theta = 5$–$30°$) besides gypsum and calcite some relatively low intensity thaumasite peaks can also be observed [15].

Nevertheless, we believe that the thaumasite attack also played its role in the damage. This belief is based on our abundant experience with concrete corrosion in consequence of ettringit development caused by the circumstances due to the specific composition of ground waters in Hungary [16–18]. The basic difference is that the damage caused by ettringit shows up primarily in crack formation while in the case of the given concrete a permanent strength deterioration not accompanied by crack formation could be observed.

Naturally, not only thaumasite (or even ettringit) formation is to be blamed for the deterioration since—as we could see—both the cement and concrete quality can also be deprecated.

Finally, before we end our presentation one could ask us what we are doing with our minor experience and evidence here when we find, among us, acknowledged experts of the thaumasite problem. The reason is, on the one hand, that we hope to broaden at this conference our knowledge in this important field. On the other hand, we intended to show how changes in the grinding technology affecting the granulometric composition of the components would influence the cement properties and thereby the corrosion resistance of the concrete.

We believe that nowadays when production of cements with limestone additive is coming again into the foreground it is not unnecessary to draw attention to these problems.

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