Deterioration of Concrete Chimneys

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Samples from two damaged concrete factory chimneys were examined. The chimneys had been exposed to severely aggressive conditions. During the field examinations, cracks in the concrete were observed in both cases. At some places the cracking was so serious that pieces of concrete were loose. Concrete samples from the chimneys were examined by X-ray diffraction analyses, chemical analyses, and by thin-section observations. The concrete from both chimneys was carbonated and in both samples sulfate reactions had occurred. Furthermore, alkali-aggregate reactions had occurred in the concrete from one of the chimneys.

•SAMPLES from two deteriorated chimneys, one located by the Mediterranean Sea and the other in Northern Europe, were investigated. The external climate of the location seemed to be of minor importance, however, compared with the chimney milieu. This environment was characterized by high temperatures, great and rapid variations of temperature, and the presence of sulfuric acid and carbonic acid.

CHIMNEY BY THE MEDITERRANEAN

The 61-meter high reinforced concrete chimney, built in 1949, had suffered damage in various sections of the shaft. The section from the base to somewhere above the beginning of the opening of the smoke inlet was practically undamaged, whereas the following section up to 16 meters above the base was seriously cracked, with larger and smaller loose concrete slabs or shells on the exterior surface, reaching in depth to the reinforcement. Similar damage was found in various places up to near the top. The reinforcement was located too far inside the outer face of the shaft, with up to 7 to 8 cm of concrete cover, and the loose concrete slabs were generally of this order of thickness. The reinforcing steel behind the slabs that cracked off the steel was only slightly corroded.

A thin section was prepared from a piece of the deteriorated concrete. From observations of the thin section, it could be concluded that the concrete was strongly carbonated along with secondary precipitations of gypsum in the cement paste. Flint pebbles with distinct symptoms of alkali-aggregate reactions were observed (Fig. 1).

CHIMNEY IN NORTHERN EUROPE

The chimney in Northern Europe was built in 1957 of reinforced concrete. In the autumn of 1965 it was inspected and it was noted that the concrete had scaled off the steel in parts of the upper 60 to 70 cm of the shaft (Fig. 2). The reinforcement was rusting and a 2-mm thick layer of rust could easily be removed. In the construction joint 13 meters from the top, loose flakes of concrete were observed 15 cm above the joint.

A concrete specimen from the top section was examined by chemical analysis, X-ray diffraction analysis, and a thin-section investigation. The concrete proved to have undergone leaching and carbonation along with the corrosion of the reinforcement. On the outer surface of the specimen, a coating of the mineral syngenite [$K_2Ca(SO_4) \cdot H_2O$] was observed (Fig. 3), while a coating consisting of the hemihydrate $CaSO_4 \cdot \frac{1}{2}H_2O$ was found on the inside of the chimney and situated in a crack in the structure.

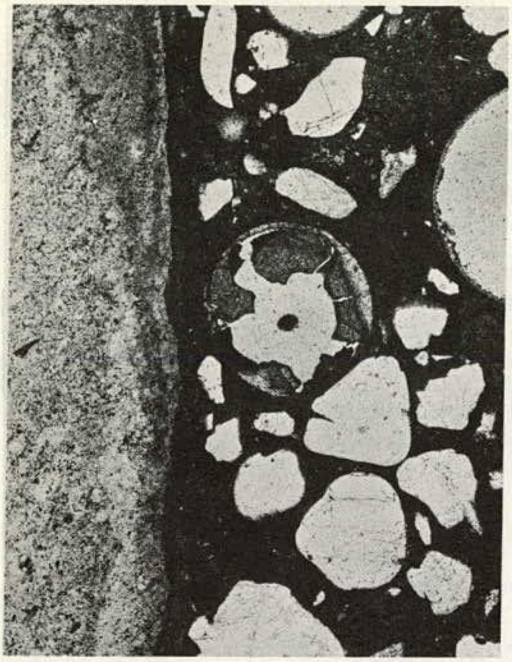

Figure 1. Thin section of concrete from factory chimney near the Mediterranean Sea. Flint pebbles to the right have darkened rim caused by partial solution resulting from alkali-aggregate reaction. Air bubble in center of picture is partly filled by alkali-silica gel, fractured during drying.

THE MILIEU OF THE CHIMNEYS

In spite of the difference in the observations from the two chimneys, it seems useful to consider them together because the milieu has a special character. Among the different factors that may contribute to the deterioration of the concrete in a chimney, the following can be mentioned:

1. The content of carbon dioxide in the smoke accelerates the carbonation of the concrete. The ability of the concrete to protect the reinforcement against corrosion is thereby reduced and formation of rust may result in spalling of the covering layer.
2. The temperature variations, presumably most pronounced at the top of the chimney, cause unequal thermal deformation of the concrete, possibly accompanied by crack formations.
3. The content of sulfur gases in the smoke condenses on the sides of the chimney, thereby developing sulfuric acid that deteriorates the concrete. The reaction products formed are gypsum and other calcium-sulfates.

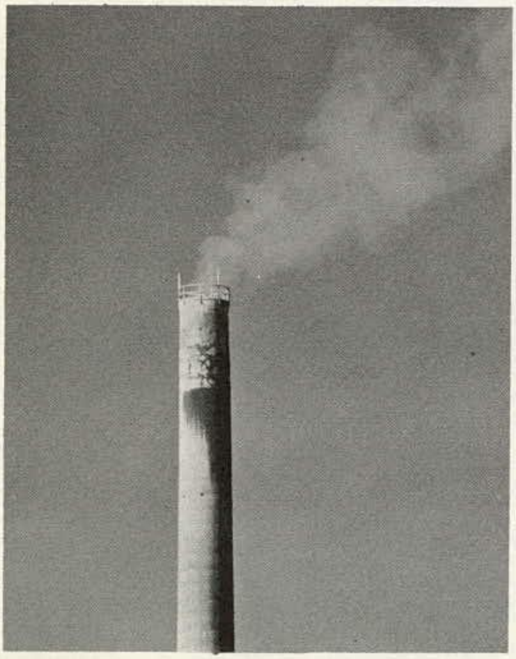

Figure 2. Top section of concrete chimney showing disintegration.

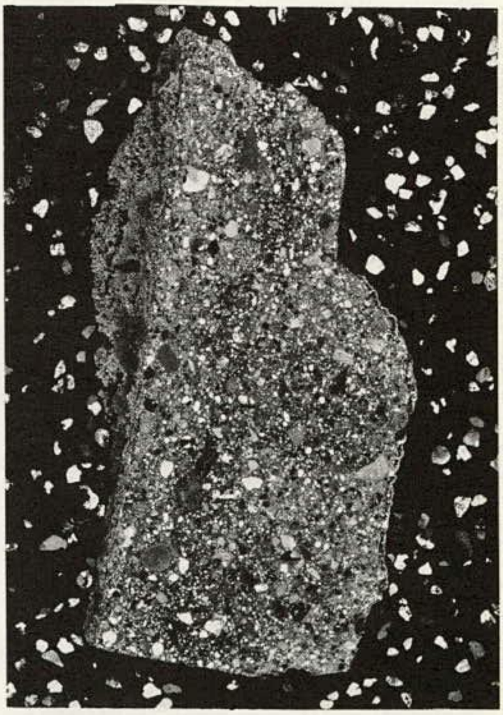

Figure 3. Total photo of a thin section prepared from a deteriorated piece of concrete taken from the outside upper part of a chimney (crossed nicols, 1.26x magnification).

DISCUSSION OF INVESTIGATION

It is supposed that a combination of the three factors mentioned previously caused the damage to the chimneys investigated. The presence of gypsum and of reacted flint pebbles in the concrete of the chimney near the Mediterranean indicates that sulfate attack and alkali-aggregate reactions in a combined action have caused a particularly rapid disintegration. The serious damage to the chimney is also caused by a too-thick concrete cover of reinforcement. The ring reinforcement, being too far away from the outer shaft face, has been unable to prevent the cracking of the outer part of the concrete as a result of tensile stress caused by the heating of the interior of the shaft.

The formation of cracks in the Northern European chimney probably resulted from the great and rapid temperature variations at the top of the shaft. But phenomena such as leaching, carbonation, and precipitation of corrosion products all contribute to a reduction of the strength of the concrete and thereby to the risk of crack formation. The coating of syngenite on the outer surface of the chimney probably came from potassium and sulfate from the smoke; the calcium may originate from either the smoke or the concrete. The presence of a hemihydrate instead of gypsum in the coating in the fracture could be explained from the temperature of the chimney.

CONCLUSION

The conclusion from the investigations is that concretes used for factory chimneys are exposed to a particularly aggressive milieu. This should be taken into consideration in construction of chimneys and reasonable precautions specified, such as (a) use of sulfate-resistant cement, (b) use of aggregate resistant to alkali-aggregate reactions, (c) possible treatment with epoxy resin, and (d) careful construction.