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Investigation of Concrete by Analysis of Thin Sections

Examen du béton par analyse de préparations en couche mince

Untersuchung von Beton durch Analyse von Dünnschliffpräparaten

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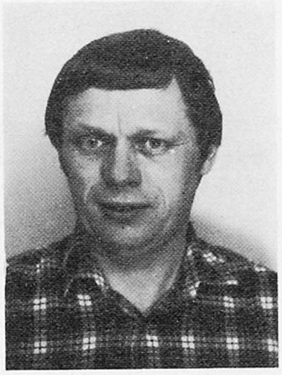

Arne Damgaard Jensen, born 1942, received his civil engineering degree at the Technical University of Denmark, Copenhagen, 1969. For three years he was involved in the construction of concrete bridges as a consulting engineer. Since 1972 at the Technological Institute, Copenhagen, dealing with inspection and investigation of concrete structures.

SUMMARY
This paper deals with the investigation of damaged concrete and with quality control of concrete. The technique of using microscopy on thin sections is described and results of such microanalyses are listed.

RESUME
L'exposé traite d'études faites sur des bétons endommagés et du contrôle de la qualité des bétons. La technique d'analyse au microscope de préparations en couche mince est décrite et les résultats de ces microanalyses sont résumés.

ZUSAMMENFASSUNG
Der Beitrag beschreibt die Untersuchung von schadhaftem Beton und zeigt Erfahrungen mit der Qualitätskontrolle von Beton auf. Die mikroskopische Analyse von Dünnschliffpräparaten wird beschrieben und die Ergebnisse dieses Verfahrens werden zusammengefasst.

1. INTRODUCTION

1.1 Normal practice

In connection with investigations of concrete buildings and other concrete constructions showing sign of deterioration after influence of the weather or other harmful action, it is normal to set up the conclusions about the type and the extent of the deterioration only based on macroscopical observations, maybe various NDT-tests, some empirical results from strength testing and chemical analyses.

The background for carrying out restoration works therefore often has been doubtful. This has led to wrong selection of repair methods and unexpected high costs.

1.2 Micro analysis

By microscopical analysis of thin sections it is possible to look inside a hardened concrete, thus obtaining a precise picture of the concrete composition and the condition of the concrete.

The technique has been developed in Switzerland. In Denmark it has been used since 1977. It is the Technological Institute which has imported and further developed some of the principles.

Micro analysis of thin sections can be used for:

- stipulation of concrete quality (young and old concrete)
- investigation of damaged concrete, mortar, tiles, bricks, natural stones, etc.)
- estimation of new products (fibre reinforced concrete, concrete with silica dust, etc.)
- improvement of concrete
- quality control of concrete, etc.

1.3 Quality control

From 1982 micro analysis has in some cases been used as a test method for quality control of newly cast concrete constructions. From the construction, a concrete element, a pavement area, a part of a bridge, one or several cores are drilled. From each core there are prepared two thin sections, which are analysed in the microscope. The following parameters are investigated: porosity, pore structure, cracks, homogeneity of the cement paste, bleeding tendency and entrapped air. An overall investigation of for instance cement type, composition can easily be made. The result of the analysis will be available one to two weeks after casting.

2. CONCRETE INVESTIGATION

2.1 General

The normal investigations of concrete structures are as follows:

- visual inspection of the structure
- examination of data on the concrete, the structure and the environment
- visual inspection of the cores, sawn longitudinally (plane cut)
- crack detection on plane cut
- air pore analysis on plane cut
- micro analysis on thin sections.

In situ testing by NDT-tests, strength testing on cores, chemical analysis, SEM and X-ray analysis, etc. may be carried out, if necessary.

2.2 Macro analysis

This analysis will reveal features about the concrete. The core is sawn longitudinally. On the plane cut the following can be estimated: stone type, stone quantity, stone segregation, type of sand fraction, colour of paste, possible air entraining, entrapped, homogeneity of mortar, effect of compaction, visible cracks, carbonation, crystallization on the surface, etc. See Fig. 1.

A more detailed knowledge of the cracks can be obtained by crack detection on the plane cut. The cut is impregnated with a fluorescent epoxy and polished: In UV-light cracks can be clearly seen now. See Fig. 2.

Information about the air pore structure is obtained by automatic image analysis of a contrast impregnated plane and polished cut. The information can be air volume, specific surface and spacing factor. See Fig. 3.

2.3 Micro analysis

The micro analysis is carried out by microscopical investigation of fluorescent impregnated thin sections as described in the next paragraph.

3. MICRO ANALYSIS

3.1 Equipment

3.1.1 Thin sections

A thin section is a 20 µm thin slide of concrete, glued on to a glass plate and covered by a cover glass. The area is normally about 50 x 30 mm. See Fig. 4.

The thin sections are prepared by grinding - step by step - an epoxy impregnated piece of concrete. A fluorescent pigment is added to the epoxy. The concrete is dried by saturation in alcohol and by evaporation to avoid crack propagation.

3.1.2 Microscope

Polarization and fluorescent microscopes are used for the analysis of the thin sections.

In the polarization microscope the crystalline components are determined, i.e. aggregates, cement particles, cement gel, different crystalline products as ettringite, calcite, calcium hydroxyde, etc. Air pores, alkali-silica gel, etc. can be identified.

In the fluorescent microscope the porosity of the different components can be identified due to the fluorescent impregnation. It is possible to see cracks down to a few µm as well as the capillary porosity of the cement paste.

3.2 The analysis

Figs. 5 - 12 show different photos from the microscope.

3.2.1 Cement paste

The volume of the cement paste in the hardened concrete is the volume of the water and the cement in the mix. The amount of cement paste can be measured by point counting, and the water-cement ratio in the hardened concrete can be determined in the fluorescent microscope. From this the original cement content can be determined.

By measuring the air content (point counting) and using the Féret formula, the strength of the concrete can be determined optically.

Normally, the cement type can be determined. The nature and the extent of different unnatural recrystallizations can be seen. A possible addition of fly ash or silica dust to the concrete can be seen. The homogeneity of the cement paste and silica dust dispersion, the formation of calcite, ettringite, alkali-silica gel, etc. can be estimated.

3.2.2 Water-cement ratio

The Technological Institute has developed a fluorescent microscopical method to estimate the water-cement ratio in a hardened concrete. In the fluorescent microscope the cement paste will shine because of the fluorescent pigment in the capillary pores. High capillarity will give a bright colour and low capillarity will give a dark colour. The method is very accurate for water-cement ratios between 0.40 and 0.60. On the basis of the homogeneity of the capillarity the efficiency of the concrete mixer can be estimated.

3.2.3 Air pore system

The air pore system can be seen in the microscope and the homogeneity can be estimated.

A concrete affected by humidity, water, dissolved salts, etc. is slowly (sometimes rapidly) transformed into ettringite, calcite, alkali-silica gel, etc. and the transformation products can often be seen in the air pores. This results in a deterioration of the concrete and a reduction of the free air pore volume, giving a reduced frost resistance and tightness.

3.2.4 Cracks

Normally, concrete contains cracks which can be observed in the fluorescent microscope. The cracks are caused by bleeding, plastic settlements, shrinkage, temperature, loading, different deteriorating actions as frost, alkali-silica reactions, sulphate attack, etc. Often the type of action causing the crack can be estimated. The cracks can be filled with the same products as the air pores and with rust from corrosion of the reinforcement.

3.2.5 Aggregates

A normal thin section contains up to about 10 coarse aggregates and 2000-3000 fine aggregates (sand particles). The ingredients of the aggregate can be estimated and it can be seen, if the aggregate has given rise to harmful deterioration in the concrete.

3.2.6 Various

The microscopical analyses of thin sections can be used to investigate different materials as mortars, tiles, bricks, natural stones, etc. This can be done in connection with investigations of deterioration, with determinations of quality and with quality control.

4. CONCLUSIONS

Up till now the Technological Institute has made about 4000 thin sections for microscopical analyses of concretes, mortars, tiles, bricks, natural building stones, clinkers, etc.

Project work is done in connection with the use of silica dust in concrete, fibre reinforced concrete and mortar, maintenance of natural building stones and monuments, etc.

The method is necessary for an internal investigation of the different materials both in connection with investigation of damages and in connection with quality control of new products, including control with repair works and restorations.

Fig. 1. Sawn cut of a concrete core with internal crack and low stone content.

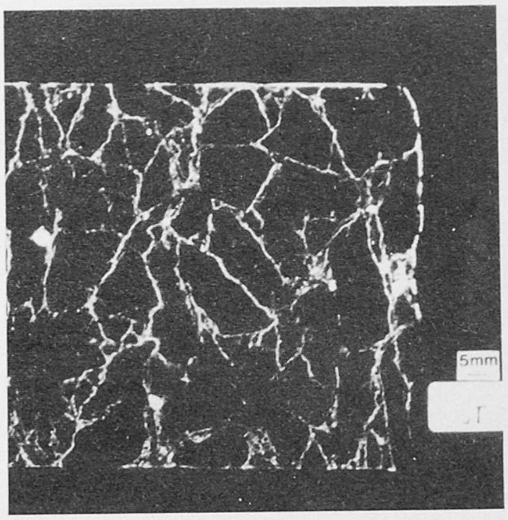

Fig. 2. Crack detection on prepared sawn cut. Heavily cracked concrete.

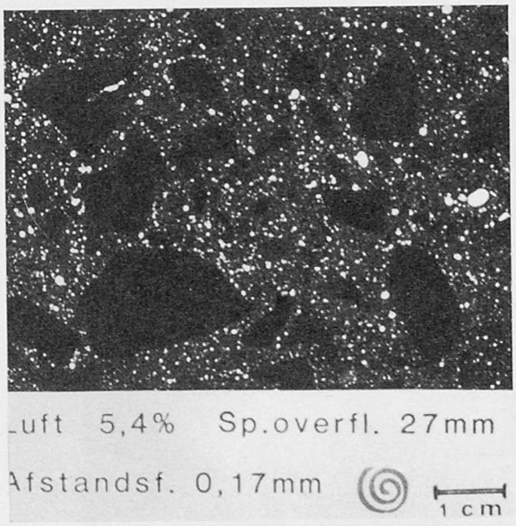

Fig. 3. Air pore analysis on contrast impregnated plane cut. A concrete with good air pore distribution.

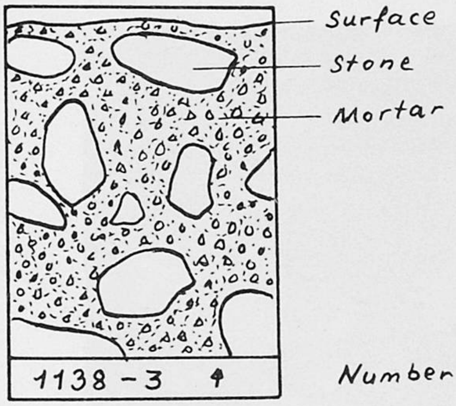

Fig. 4. Sketch of a thin section, 1:1.

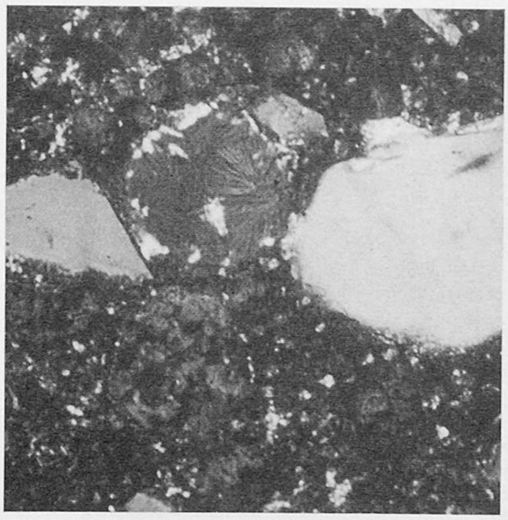

Fig. 5. Polarization. 160x.
Air pore filled with $Ca(OH)_2$ and ettringite. $Ca(OH)_2$-crystals in the cement paste.

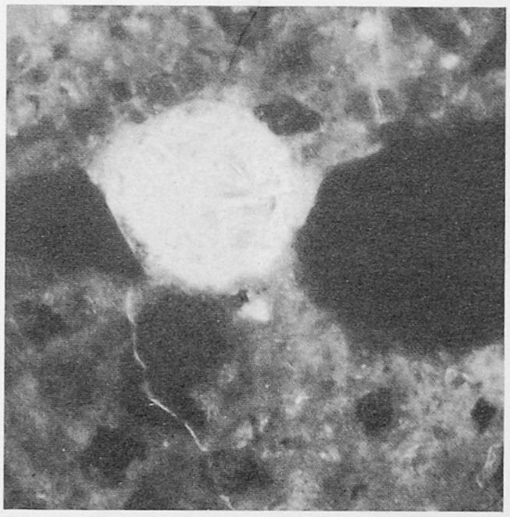

Fig. 6. Fluorescence. 160x.
The same area as Fig. 5. Small cracks in the cement paste.

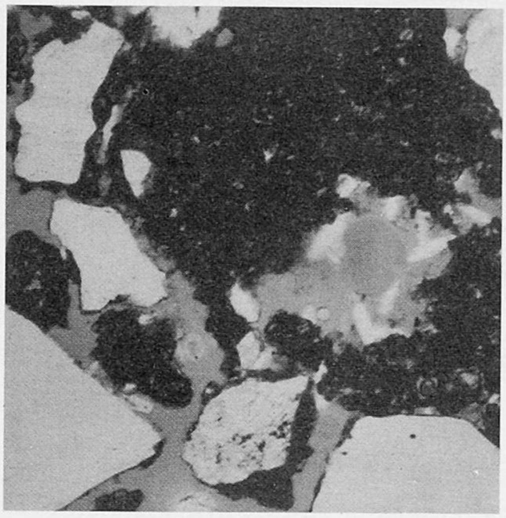

Fig. 7. Polarization. 65x.
Badly mixed cement mortar with cement paste lumps and entrapped air. Big $Ca(OH)_2$-crystals in the air pores.

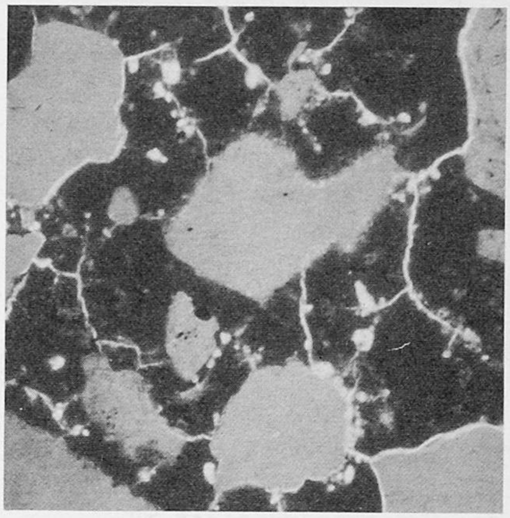

Fig. 8. Fluorescence. 65x.
Dense cement paste with many micro cracks in a concrete containing silica dust.

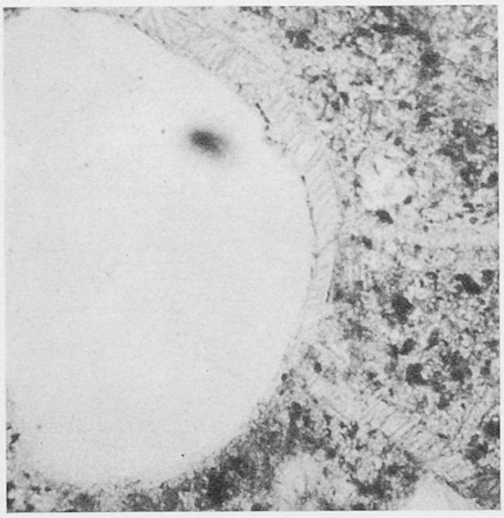

Fig. 9. Polarization. 160x. Micro cracks filled with ettringite.

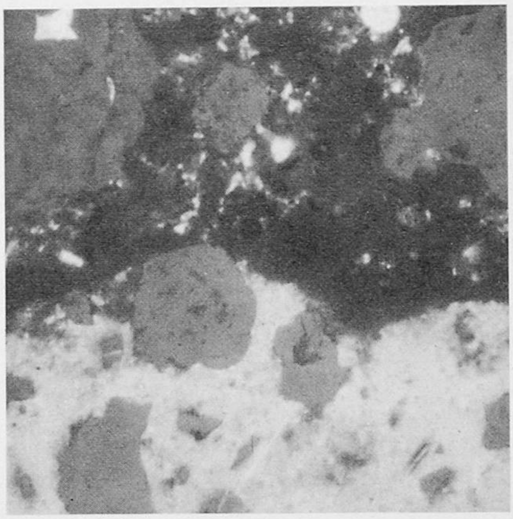

Fig. 10. Fluorescence. 65x. Joint between old (porous) and new (dense) concrete.

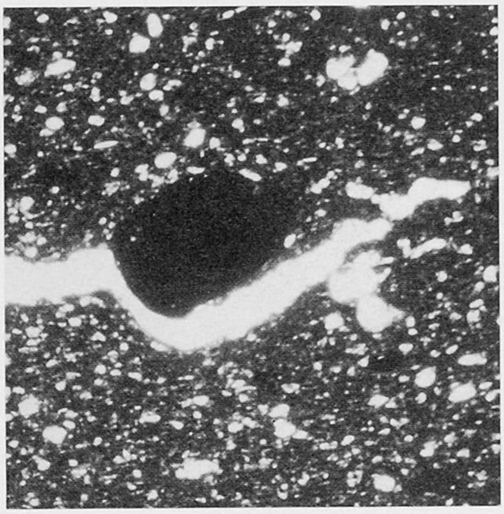

Fig. 11. Polarization. 65x. Production crack in a tile with bad frost durability.

Fig. 12. Fluorescence. 65x. Surface parallel cracks in a clay containing limestone used as building stone.

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