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Monitoring of Corrosion Processes in Chloride Contaminated Mortar by X-Ray Tomography

Monitoreo con tomografía con Rayos X del proceso corrosivo en mortero contaminado con cloruro

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Abstract

Corrosion of steel reinforcement in concrete exposed to chloride containing environment, is a serious problem in civil engineering practice. Electrochemical methods, e. g. potential mapping, provide information whether the steel reinforcement is still passive or depassivation has been initiated. By applying such techniques no information on the type of corrosion, its extent and distribution of corrosion products is available. Until now it is impossible to collect such information without destroying specimens after electrochemical testing has taken place. To overcome this problem it was tried to study the steel surface within the mortar specimens by X-ray tomography (CT). Within the scope of these investigations it could be shown for the first time, that X-ray tomography is suitable to make corrosion pits on rebars visible which are embedded in a mortar with a cover thickness of about 20 mm. Furthermore, sections of embedded bars formed by CT-measurements were successfully compared to metallographic sections.

Key words:Self-corrosion, X-ray tomography, reinforcement, concrete parameters, metallographic sections.

Resumen

La corrosión del acero reforzado en concreto expuesto a ambientes que contienen cloruro es un serio problema en la práctica de la ingeniería civil. Los métodos electroquímicos, vale decir, el mapeo potencial, suministra información acerca de si el refuerzo todavía es pasivo o se ha iniciado la despasivización. La aplicación de tales técnicas no suministra información sobre el tipo de corrosión, ni sobre la extensión y distribución del producto de la corrosión. Hasta hoy es imposible recopilar tal información sin destruir los especímenes, luego de que la prueba electroquímica se lleva a cabo. Para superar este problema se trató de estudiar la superficie del acero dentro del mortero de los especímenes, mediante las tomografías con Rayos X (CT). En el marco de estas investigaciones se pudo mostrar, por primera vez, que la tomografía de rayos X es apropiada para hacer visible la corrosión de las barras de refuerzo empotradas en el mortero, con un recubrimiento de unos 20 milímetros. Posteriormente, secciones de las varillas empotradas formadas por las medidas del CT, fueron exitosamente comparadas con las secciones metalográficas.

Palabras clave: Autocorrosión, tomografía de rayos X, refuerzo, parámetros de concreto, secciones metalográficas.

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1 Introduction

Corrosion of steel reinforcement in concrete exposed to chloride containing environments ís a serious problem in civil engineering practice. Electrochemical methods, e.g. potential mapping, [1,2] provide information whether the reinforced steel ís still passive or depassivation has been initiated. By applying such techniques no information on the type of corrosion, its extent and distribution of corrosion products is available. Until now it is impossible to collect such information without destroying specimens after electrochemical testing has taken place. Within the scope of a research project [3] the part of self-corrosion of the total corrosion was analysed [4]. In the self-corrosion measurements a number of fluctuations of the electrochemical values of the same series was recorded [5, 6]. It is important to notice that the aim of this examination is to correlate the electrochemical values to the real steel surface. For this purpose the dismantled steel surface of one specimen (after a certain period of time), is correlated to the electrochemical values of the whole series. From the observations obtained so far it can be concluded that due to the different conditions of each specimen this procedure has to be used with caution. The electrochemical values give information about trends but no absolute data about the development of self-corrosion. The real appearance of the steel surface can only be observed by the dismantled steel cylinder, after destroying the concrete cylinder. Therefore an ongoing observation of the same steel surface is not possible.

To overcome this problem it was tried to study the steel surface inside the mortar specimens by X-ray tomography (CT). Other investigations on mineral building materials [7-12] showed realistic possibilities. In this publication for the first time the applicability of X-ray tomography to observe corrosion processes in chloride contaminated mortar is documented.

2 Experimental

2.1 Electrochemical pre-damaging

In contrary to specimens in a german research-project [3], for the examination by X-ray tomography, a simplified experimental arrangement was used (Fig. 1). Mortar cylinders with a height of 90 mm and a diameter of 40 mm were used. The mortar was produced according D1N-EN 196-1 [13] with 6.0% chloride by weight of cement. Steel bars (S 235 JR G2), with a length of 100 mm, a diameter of 8 mm and with as-received surface (with mill scale) were embedded in the middle of the samples. Before embedding, the steel bars (working electrode) were degreased and the upper side coated with a lacquer. A wire made of mixed titanium oxide was embedded, and used as counter electrode.

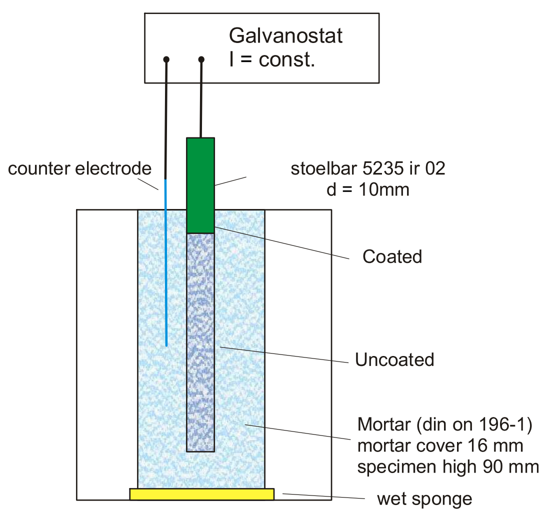


Fig. I: Specimen and experimental arrangement for electrochemical pre-damaging

After producing the mortar cylinders, they were stored for *28* days according to DIN EN 196-1 [13]

At first, all embedded bars were pre-damaged by static galvanostatic polarization (10 mA/cm^2). ln order to increase the conductivity and to minimize the mobility of iron ions and thus the migration of ions away from the working electrode the specimens were placed on a wet sponge. The specimens were damaged in cycles, 24 hours pre-damaging and 3 days storing. This cycle was applied five times. After 5 cycles of pre-damaging the specimens were investigated by X-ray tomography. Subsequently, the mortar cylinders were destroyed and the bar dismantled, cleaned and documented by photography. After the investigation of X-ray tomography the dismantled steel bar was carved and metallographic sections prepared in significant levels of the bar.

2.2 CT-Examination

The measuring system for the 3D-computer tomography consists of a X-ray tube, a manipulator and a detector. The experimental arrangement is shown in figure 2. This Ls realised by rotation of the test object r in the X-ray cone beam. A radiography of the test object for many different viewing angles is taken. The radiography is an image of attenuation of the primary X-ray beam by differences in material density and material thickness. The choice of appropriate X-ray energy is a parameter influenced by the geometry and the material compound of the testing object. The specimen volume is reconstructed from all radiographic images.

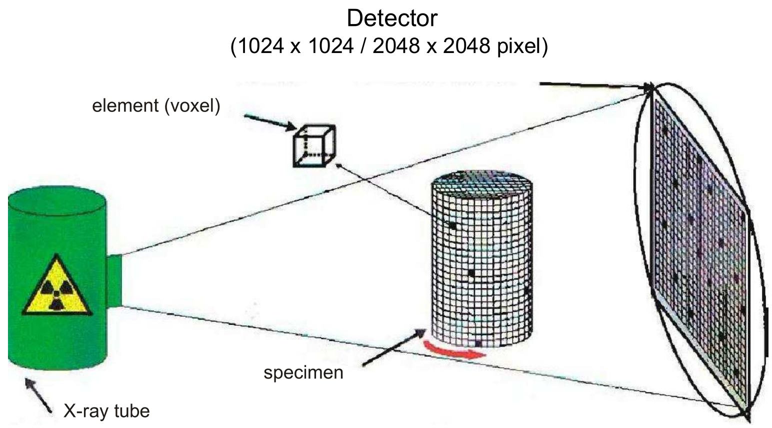


Fig. 2: Principal configuration of computer tomography

The usage of a X-ray tube with small focal spot (micro focus X-ray-tube) and magnification technique enables a high resolution. A flat panel detector with 2048 x2048 pixel was used as detector, whereas 4 elements were combined (binning 2). The parameters were: X-ray energy 200 kV, lOOmA. A prefilter of 0.3 mm Cu + 1.0 mm Ag was selected to reduce the beam hardening artefact.

The number of frames for one revolution was 900/360°. The magnification was 9.2. The reconstructed image matrix had a volume of 1023 xl023 x915 pixel. This corresponds to 915 slices with 1023x1023 pixel. The spatial resolution (voxel size) was 45 mm^3. The X- ray absorption in each voxel, represented by the material specific X-ray absorption coefficient, was normalized to 8 bit grey values.

3 Results

In figure 3 the destroyed mortar cylinder is documented. On the surface of the steel bar and in the mortar around the bar, corrosion products can be detected. The more pronounced display of corrosion products at the bottom of the mortar cylinder are a result of the higher moisture in this area. It is obvious, that the iron ions are less mobile in the higher areas of the specimen then at the bottom, as expected. In the left side of figure 3 the offprint of the rebar is shown. Obviously, the movement of the corrosion products in this area has been reduced by lower moisture in the specimen. The combination of less moisture and temporary pre-damaging led to a realistic damage symptom.

In a next step the cover mortar were removed and the dismantled bar was cleaned from mortar and corrosion products.

In figure 4 the lower area of the bar is shown in two views. On the left side the result of the 3D X ray tomography of the embedded bar and the right side a photo of the dismantled bar in the same position are shown. It is obvious that a realistic picture of the embedded bar is given by the X ray tomography. Some significant points on the steel surface (1-10) were marked in the picture of the X-ray tomography and the photography of the same bar.

In order to get information on the extent and size of pits their dimensión were measured. The results are presented in table 1.

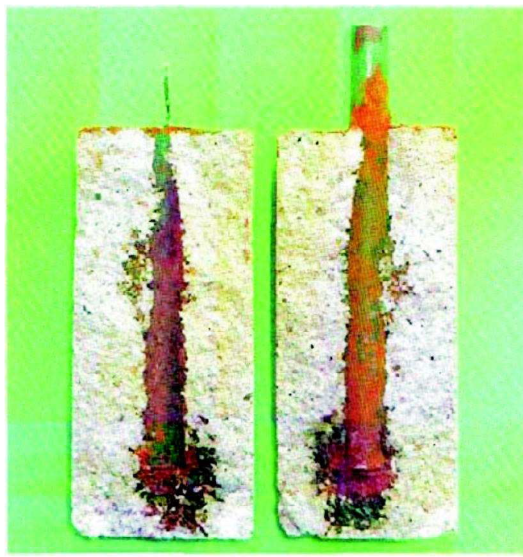
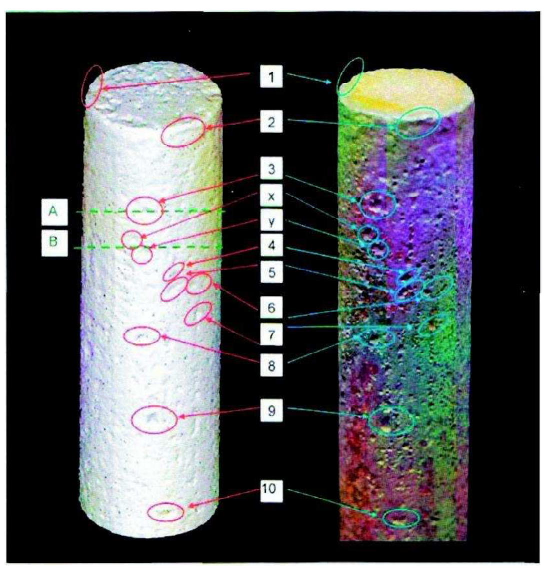


Fig. 3: Destroyed mortar specimen



Fig, 4: Comparison berween embedded steel bar (CT, left) and dismantled steel bar (photography, right)

Table l: Diametei' and depth of seleeted pits

location	diameter	depth	unit
4	610/ 500	158	[¿im]
5	950	120	[nmj
6	310	150	[>m]
8	202	50	[|im]
9	680	271	|>m]

Additionally in some levéis (sections A, B) rcpresentative pits (1-10. X, Y) were marked, and metallographic sections were selected (figure 5, 6), Figures 5 and 6 shows the comparison bctwcen a metallographje section and a section created by data of X-ray tomography. Therefore the outline of the metal lographic section was insulated and superimposed with the section from CT-analysis in the same level. It can be recognized that there is a good correlation between metal lographic sections and section from CT- data. So it is obvious that it is possible to give a realistic picture from inside the specimen by this technique, without destroying the specimen.

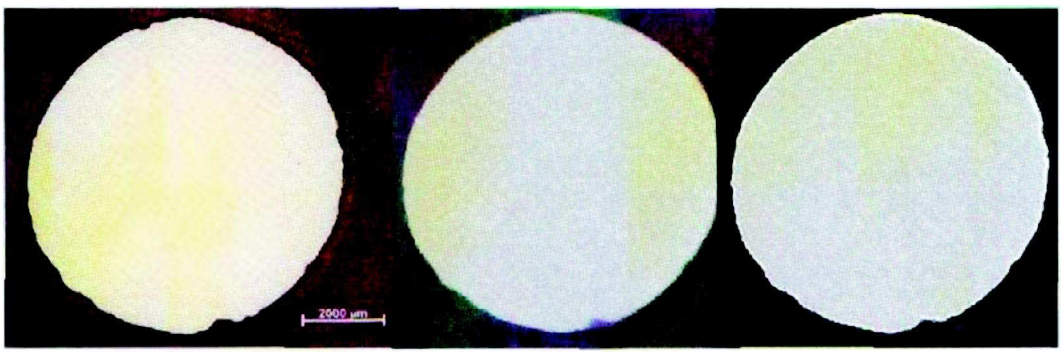


Fig. 5: Level A, comparison bcrween metallographic section (pho lograph y, left) and section using data from X-ray tomography (CT, middlc), superimposition of outline from metallographic section with section froin X-ray tomography (right)

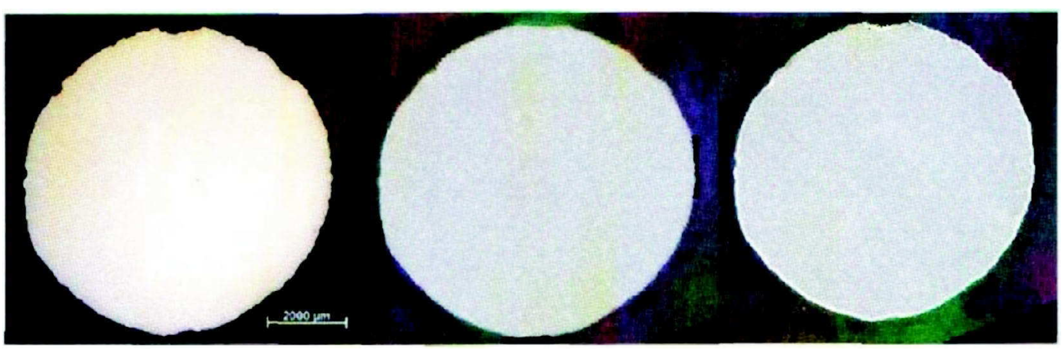


Fig. 6: Level B, comparison between metallographic section (photography, lefi) and section using data from X-ray tomography (CT, niiddlc), superimposition of outline from metallographic section with section from X-ray tomography (righl)

Aim of these investigafioas was to analyse the possibility to give a realistic picture of the specimen surface without destroying the specimen. Moreover it was possiblc to highlight different levels of the specimen by X ray tomography and to survey the local pits.

4 Discussion

Within the scope of these investigations it could be shown for the first time, that X-ray tomography is suitable to visualise corrosion pits on rebars which are embedded in a mortar with a cover thickness of aboiit 20 mm. F,vcn pits smaller than 50 pm could be detected bv X-ray tomography. The residís from the X-ray tomography investigations were verífied by inspection of (he real surface of the dismantled bar and by different metallographic sections. From the rcsults obtained so far it can be concluded that in principie C í is suitable to detect corrosion pits on embedded steel bars. Furthermore, for the first time this method enables to observe corrosion pits and íts growth in-situ without destroying the specimcns. In addition it can be made a realistic plañe geometry of thosc pits in different levels by sections from CT-data.

This allows to reduce the high amount of sainples that is normally necessary for corrosion investigations of reinforcement corrosion.

5 Conclusions

Within the scope of examining steel specimens embedded in chloride contaminated mortar X-ray tomography was used to analyse the areas, damaged by chloride induced corrosion. Damaged areas with dimensions of a few micro meters could be detected and surveyed. The results of the X-ray tomography were verified by inspection of the surfaces of the bars and metallographic sections after removing the cover mortar.

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