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# MECHANICAL AND CORROSION BEHAVIOUR OF ENCAPSULATED SHIELDING-CONCRETE CONSTORIT® IN THE CONSTOR® WALL - TEST PROGRAM AND FIRST RESULTS -

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## 1 Introduction and motivation

The CONSTOR® ADV is a transport and storage cask for spent fuel elements of the new generation. Its wall is a sandwich system composed of steel - CONSTORIT® - steel. CONSTORIT®, is a shielding material consisting of iron aggregate frame and hardened cement paste, that is hermetically encapsulated between the inner and outer steel liner. The cask inventory causes high temperatures of up to 180°C within the cask wall requiring an improved wall design. Therefore, in addition to CONSTORIT®, copper heat conducting elements are inserted between the steel liners **(Fig. 1)**.
A bibliography research concerning the behaviour of hermetically encapsulated concrete under increased temperatures and the compatibility of materials of the 3-material-system iron-copper-concrete have confirmed the basic suitability of the material combination. However, this could not lead to further findings.
Due to the high pH-value of the hardened cement paste and the limited availability of corrosion media it can be assumed that the 3-material-system of the CONSTOR® wall does not bear a high corrosion risk.
In order to confirm this statement and to learn more about the material properties of CONSTORIT® and the long-term behaviour of the material combination of the CONSTOR® wall, two test programmes have been designed and started. During the development of the test programmes, temperatures and types of irradiation a cask wall may be exposed to are taken into account.
This lecture describes the test programmes and presents the initial results.

## 2 Objective of the test programmes

It is the objective of the test programmes to prove that the materials used for the cask wall will not show signs of inadmissible corrosion during the scheduled utilisation period of a cask. Furthermore, the mechanical properties of CONSTORIT® are to be determined.
For this purpose the following two test programmes have been developed:

1. Test program for the determination of mechanical property values of heavy concrete in dependence on the temperature and storage period.
2. Test program for the corrosion behaviour of the 3-material-system in dependence on the temperature and storage period.

## 3 Implementation of the test programmes

### 3.1 Test program for the determination of mechanical property values of heavy concrete

#### 3.1.1 Selection of the tests

Important for the mechanical design is the understanding of the strength development of CONSTORIT® at high temperatures over a long period of time. Especially the compressive strength and the dynamic e-modulus are of interest here. Therefore uni-axial and tri-axial concrete pressure tests at different confining pressures as well as the determination of the dynamic e-modulus have been selected. For the tri-axial pressure tests the effect of the expansion impediment of the concrete by the steel liners and also by the adjoining CONSTORIT® are modelled.
In addition, the porosity and the moisture content of the hardened cement paste of CONSTORIT® are determined. At temperatures above 100°C steam develops in the cask wall due to the water in the hardened cement paste. In order to minimise the developing pressure a large part of the hardened cement paste contains inflated pores. This part is identified by the measurements.
Size and diameter of the specimen mould depend on the heterogeneous composition of the concrete and the largest particles of the iron aggregates as well as the boundary conditions of the irradiation tests.

### 3.1.2 Preparation of a specimen and its storage

Cylindrical CONSTORIT® specimens are prepared with a diameter of approx. 99 mm and a height of approx. 100 mm. All CONSTORIT® specimens are hermetically encapsulated in a thin-walled mould **(Fig. 2 A)** and stored at +20±2°C until the 56th day. In order to be able to strip the CONSTORIT® specimens undamaged even after a long storage period at high temperatures, they are removed from the mould and enclosed in slightly larger, thick-walled steel moulds. This also models the situation of CONSTORIT® in the cask wall. The result are specimens **(Fig. 2 B)** resisting the steam pressure generated inside at high temperatures. Afterwards the specimens are stored until they are tested at different temperatures (+20°C, +110°C and +190°C) and types of irradiation possibly occurring within the cask. The selected storage periods are 3 and 6 months and 1 and 2 years. The storage periods are shown in **Fig. 3**.

### 3.1.3 Tests

For each series of tests and temperature storage the following property values of CONSTORIT® are determined:

- uni-axial compressive strength
- tri-axial compressive strength with a confining pressure of 40 MPa
- dynamic e-modulus
- bulk density and moisture content of CONSTORIT®.

In addition, after 3 months of temperature storage also the tri-axial compressive strengths of the CONSTORIT® specimens are tested with a confining pressure of 5 and 75 MPa, and hardened cement paste specimens are used to measure the bulk density as well as the void ratio of the hardened cement paste. Schematic drawings of the compressive strength tests are shown in **Fig. 4**.

### 3.1.4 Results

**Fig. 5** shows the CONSTORIT® specimens before and after the pressure tests. Clearly recognisable is the disintegration of the specimens after the uni-axial pressure test. After the tri-axial pressure test the specimens are upset and show cracks typical for a fracture, they are, however, not completely fractured. The results of the compressive strength tests are shown in **Fig. 6**. The uni-axial compressive strengths achieve the strengths expected for this concrete composition. Uni-axial tests were performed on a standardised pressure test machine as well as by the tri-axial pressure test machine, in order to be able to compare the two measurements. The measured results show the same concrete strengths, and the scattering of the measurements is within the usual scope for concrete. The mean values of the compressive strengths have been determined by at least 3 measurements. The diagram clearly shows the effect of the lateral expansion impediment of the CONSTORIT®. A confining pressure of 40 MPa more than triples the compressive strength compared to the uni-axial compressive strength.

## 3.2 Test program concerning the corrosion behaviour of the 3-material-system

### 3.2.1 Selection of the tests

The compatibility of the materials used for the CONSTOR® wall shall be ensured at high temperatures. They should not react with one another in a manner that may adversely affect safety. Therefore the corrosion behaviour of the 3-material-system is tested with specimen, which model a section of the cask wall and which store at different temperatures. To find out, if corrosion occurs, the specimen will be opened after storage and the connecting points of the different materials will be checked visual and with metallographic tests.

### 3.2.2 Preparation of specimens and storage

Specimens **(Fig. 7)** are prepared, which model a section of the cask wall. For this, a bottom of austenitic steel is welded to one end of a ferritic steel pipe. A copper plate is placed in the centre of the form lodged between the bottom and the cover plate by closing the pipe section. The remaining cavity is immediately filled with iron aggregate. Then the cover plate (ferritic steel) is welded on. By injecting the cement paste **(Fig. 8)** the remaining gaps of the mould are filled and the specimen is completed. After the injection is completed the openings for the injection are hermetically encapsulated.

The specimens formed by this are all stored at approx. +20°C until the 56th day. Afterwards they are stored at different temperatures (+20°C and +190°C) as well as under additional irradiation until the test is performed. The selected storage periods are 3 and 6 months and 1 and 2 years. The storage periods are shown in **Fig. 9**.

### 3.2.3 Corrosion tests

After storage, the corrosion behaviour test of the 3-material-system is performed on all specimens. For this the specimens are opened and the metal surfaces as well as the iron aggregate of the CONSTORIT® are visually examined with regard to signs of corrosion.
Here the following contact points are examined **(Fig. 10)**:

(1) Copper plate – austenitic steel (inner liner)
(2) Copper plate – ferritic steel (outer liner)
(3) Copper plate – CONSTORIT®
(4) CONSTORIT® – ferritic steel (outer liner) and
(5) CONSTORIT® – austenitic steel (inner liner).

The inspection includes:
- visual examination personal, with light-optical microscopy and SEM
- dye-penetration tests
- cross-sections as microsections of the metal specimens.

The latter are required, to exclude signs of deeper corrosion, such as intercrystalline corrosion.

### 3.2.4 Results

So far, the tests performed on the specimens after a storage period of 56 days at ambient temperature show that all metal surfaces inside the specimens developed a slight superficial corrosion, comparable with a short-term storage with the exposure to air. SEM and LOM tests on selected metal specimens detected no deeper corrosion. **Fig. 11**. show for example three different places where the iron aggregates are in contact with stainless steel, ferritic steel and copper. Intensive metallographic investigations shows that there was no indications of any inter- or transcrystalline corrosion. This confirms that due to the high pH-value of about 11 to 12 and the limited quantity of corrosive media the structure and material of the cask wall has not been damaged significantly. The shielding characteristics and the stability of the wall are maintained.

## 4 Summary and outlook

The results achieved so far supply information about the behaviour of the CONSTOR® wall materials at ambient temperature. After a storage period of 2 months the hermetically encapsulated specimens were opened and different tests were performed on the specimens.
The results of the compressive strength tests on CONSTORIT® specimens show that the shielding concrete achieves a strength of at least 50 MPa and with a cask sidewall pressure of 40 MPa the strength is increased up to 193 MPa. This result matches the experience of conventional concrete tests and shows that these are tests suited to determine the compressive strengths of the concrete.
Visual and metallographic tests were performed on the specimens of the 3-material-system "copper-iron-concrete" with regard to signs of corrosion. All metal surfaces show slight superficial corrosion inside the specimen. It is comparable with the signs of corrosion after a short-term storage with the exposure to air. A significant removal as well as inter- or transcrystalline corrosion, however, could not be found in any specimen. Therefore structure and material of the cask wall are not damaged significantly due to the high pH-value of about 11 to 12 and the limited amount of corrosive media. The shielding characteristics and the stability of the wall are maintained.
Further tests will show, if this condition is maintained after years of temperature stress. An expansion of the programme will include the tests at high temperatures as well as the effect of gamma rays and neutron radiation on the material combination.

## 5 Figures

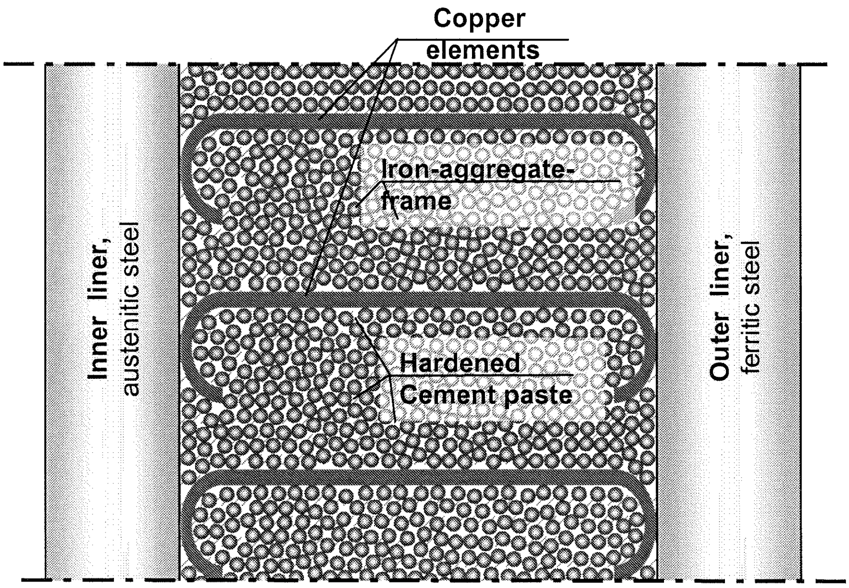
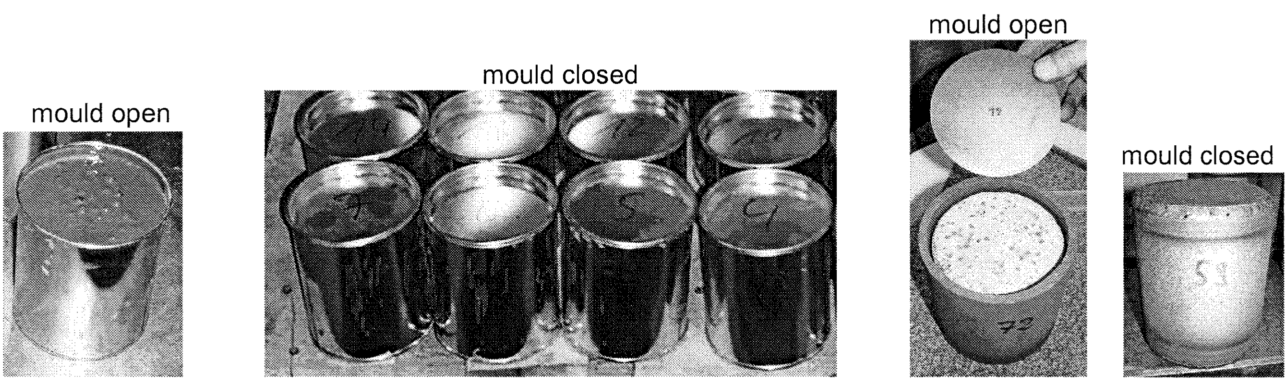



**Fig. 1** Design of the CONSTOR® wall




A specimen in thin-walled mould

B specimen in thick-walled mould

**Fig. 2** Specimen for mechanical property in the moulds

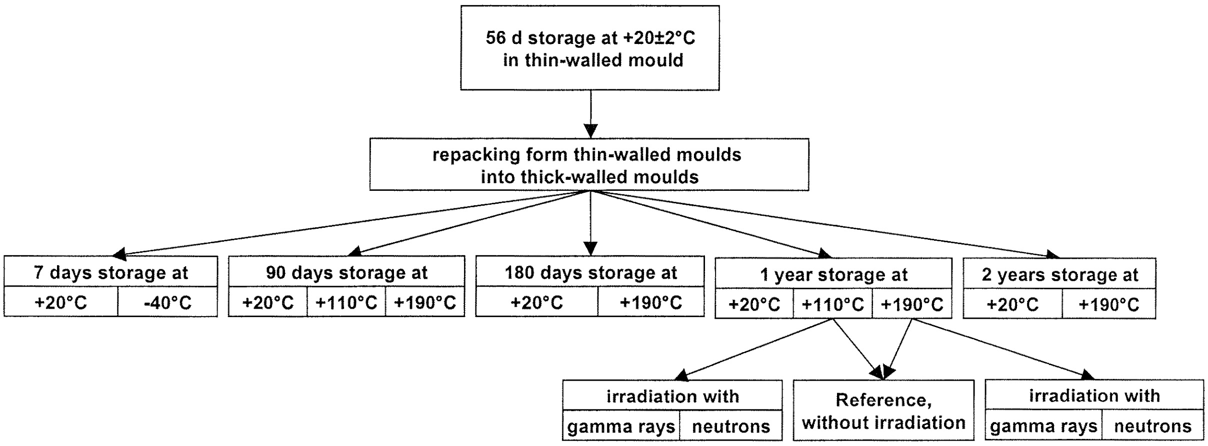



**Fig. 3** Partitioning of the specimen for mechanical property for storage types

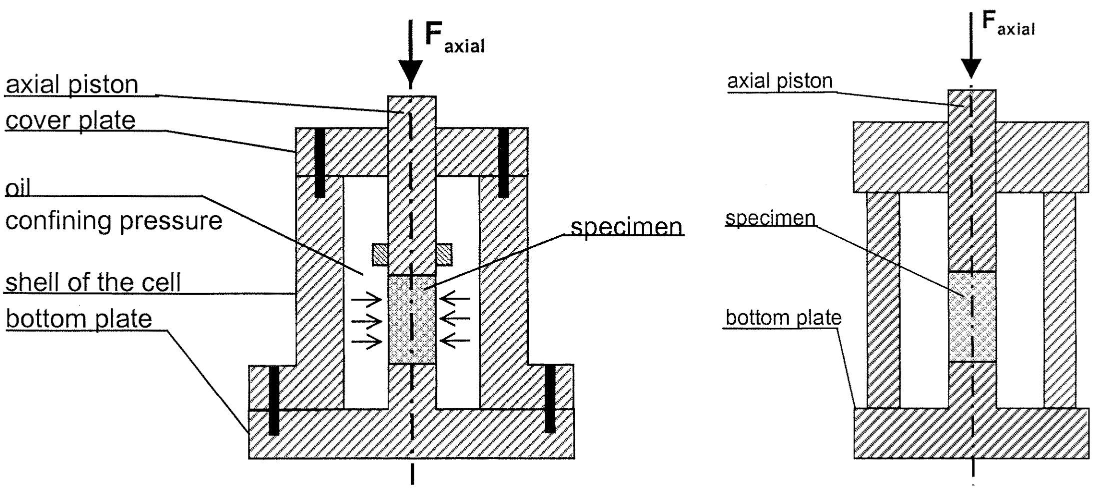
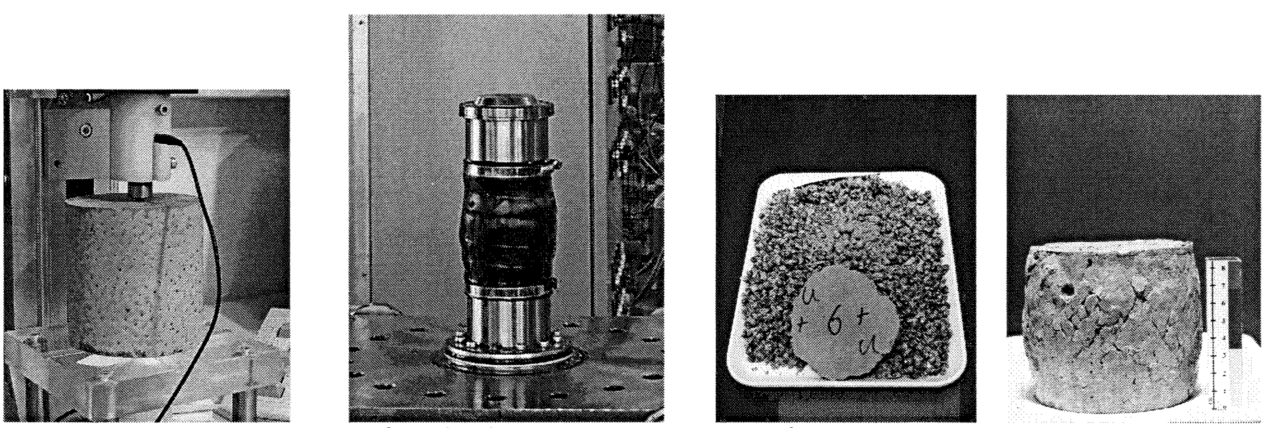



**Fig. 4** Principle drawing of a tri-axial pressure test machine and uni-axial pressure test machine



during dynamic e-modulus test | after tri-axial pressure test in oil resistant sheathing | after uni-axial pressure test | after tri-axial pressure test

**Fig. 5** CONSTORIT® specimen before and after different kinds of tests

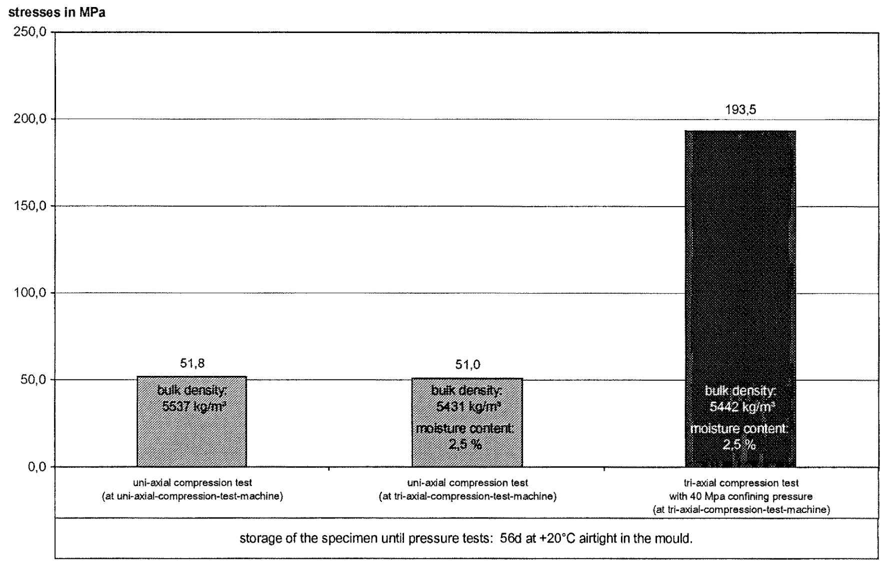
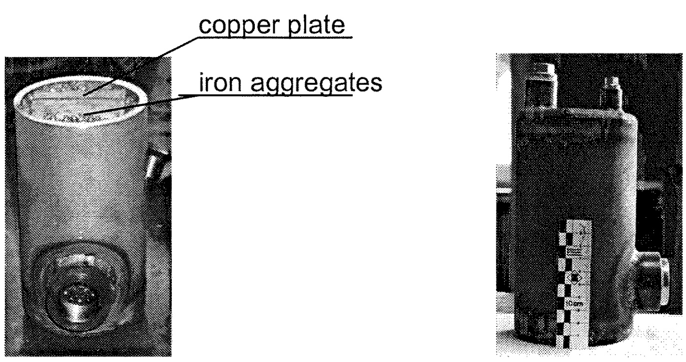



**Fig. 6 Average values of CONSTORIT® compressive strengths after storage at +20°C**




opened specimen mould before closure

closed 3-material-specimen

**Fig. 7** Example of a 3-material-specimen for corrosion tests

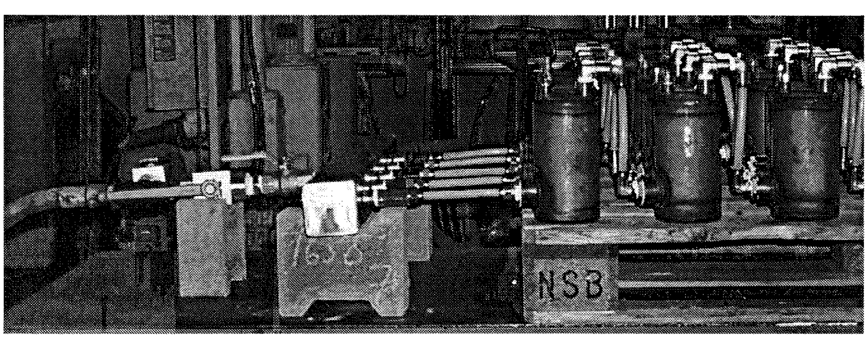



**Fig. 8** Injection of cement paste into 3-material-specimen

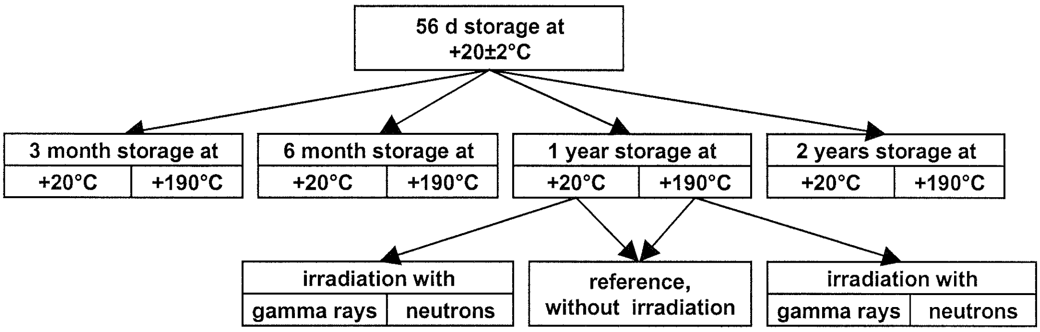



**Fig. 9** Partitioning of the specimen for corrosion tests for storage types

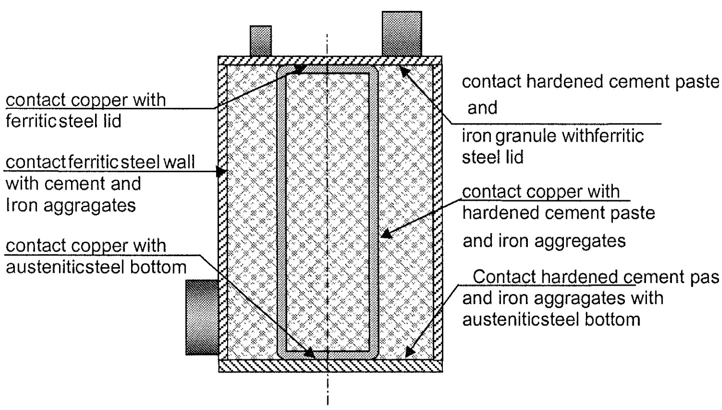
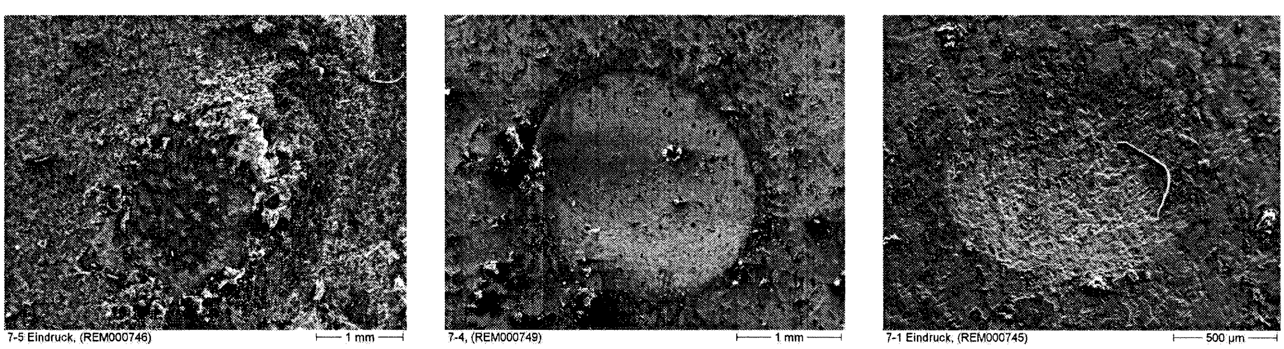



**Fig. 10** Sampling places in the specimen for corrosion tests of metal samples and iron aggregates




**A** **B** **C**

**Fig. 11** SEM footprints of iron aggregates on the base-materials austenitic steel (A), ferritic steel (B) and copper (C) in the specimen for corrosion tests