Determination of the suitability of technical textiles for cathodic corrosion protection

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ABSTRACT: Cathodic protection (CP) is a widely used method to protect steel reinforcements against corrosion. In the course of the last half century, it has been established as a proven system for repairing corrosion-affected reinforced concrete structures, which have mainly been damaged by chloride-induced corrosion. The impressed current anode system for the protection of steel in concrete is latest state of technology. The anodes are embedded in mortar on the repair structure surface and exposed to external current. In this way, the potential of carbon steel is shifted in cathodic direction and the anodic dissolution of carbon steel is suppressed. The current densities on the surface of the reinforcement play a key role in the shifting of the potential in cathodic direction. Nowadays, Mixed Metal Oxide coated Titanium (MMO) is used as an anode material for CP due to its high durability under anodic Polarization. Materials such as carbon fibers are being studied.
Carbon textiles in combination with mortar, which present high mechanical properties and are also conductive, are considered. The use of carbon textile as an anode material for the above purpose has not been studied so far. Studies are being carried out in order to evaluate the potential of different carbon-textile anodes and different mortar mixtures for the cathodic protection of steel in concrete. In order to evaluate the polarization behavior of carbon-textile in mortar, Galvanostatic experiments were performed. Based on these experiments, current density-potential-curve was derived.

1. Introduction

In order to protect the corrosive constructions and restrict the cross-sectional reduction of the reinforcement, repair actions are required. To achieve this objective, it is necessary to inhibit one of the two partial reactions during the corrosion process that cause the corrosion processes come to a halt. The Cathodic Protection (CP) is allocated to the process, which suppresses the anodic partial reaction. The cathodic corrosion protection with impressed current anodes has been a proven, excellent method for the protection of constructions against corrosion for many decades now. An advantage of the CP is that chloride induced concrete does not have to be removed and almost non-destructive repair is still possible.

Figure 1 illustrates the principle of the CP as follows: By embedding an inert anode, the reinforcement is applied selectively via a DC source with an impressed current. This current causes an excess of electrons in the reinforcement which makes the reinforcement act as a cathode because the electrochemical potential of the steel has been shifted in the negative direction. Therefore, the corrosion processes that the protective current was applied to come to a halt, or are reduced to an acceptable level.

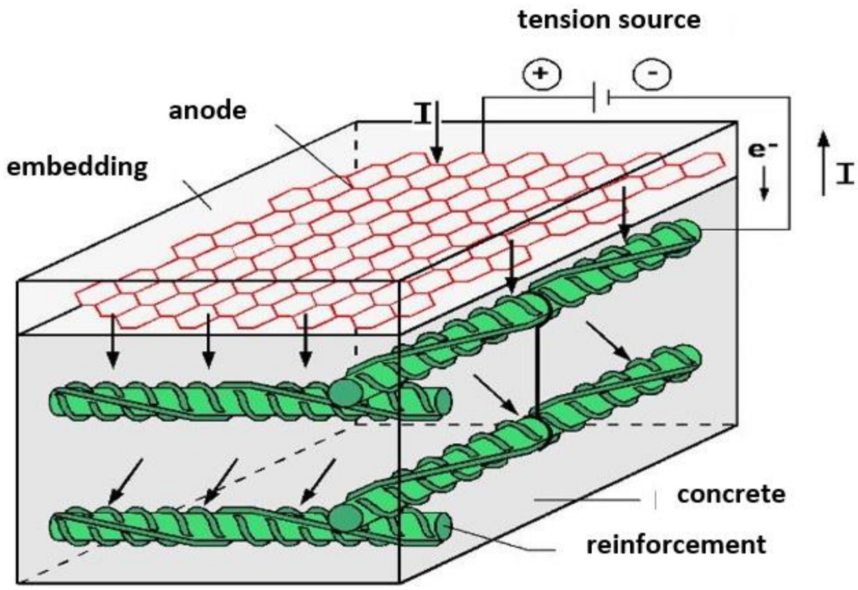

Figure 1: Concept of cathodic protection with an inert external-current-anode

To prevent the anodic dissolution of iron, a CP system for uncoated steel in corrosive existing buildings is typically operated at current densities between 2 mA/m^2 to 20 mA/m^2.

If the component, however, is continuously saturated with water, a current density of 0.2 mA/m^2 to 2 mA/m^2 can be considered.

2. Textile Concrete

Textile concrete consists of a composite system of cement with glass or carbon fibers as a reinforcement material. By using this material, it is possible to achieve low component thicknesses as the tensile strength is increased.

Conventional CP systems located on the market function with titanium mixed oxide as anode material. However, the use of technical textiles as anode material would have disadvantages to this method. Compared to traditional repair measures, the use of Textile Concrete is considered to be more environmentally friendly and the repair of a corrosion-damaged component could be more resource-efficient and cost-effective.

3. Experiment setup and test procedure

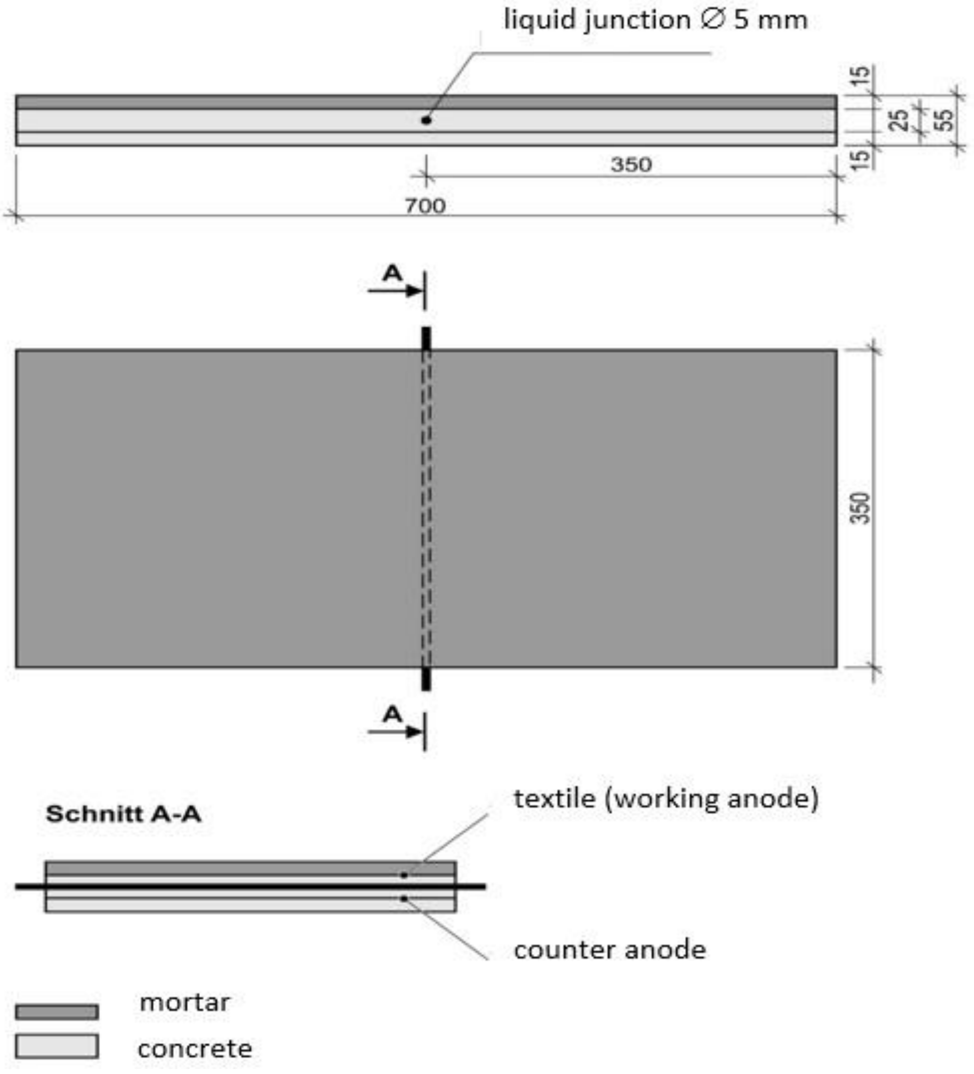

Figure 2: Detail drawing of the specimen – Dimension [mm]

This structure was selected to simulate a component surface. The undermost layer of concrete containing reinforcement (hear: MMO), while the subsequent layer of concrete simulate the concrete cover. To simulate the reinforcement was used the MMO, because this material can produce a homogeneous electric field due to its chemical inertness and reticular structure. Carbon Textile is applied onto the component surface by means of the special developed mortar. Thus, a renovation of a corrosion-damaged concrete component is simulated. For the later measurements were required reference electrodes, the electrolyte bridges were placed in specimens. This electrolyte bridge was filled for a later connected with silver-silver chloride solution, which corresponds in our measurements the reference electrode.

Figure 3: Installed liquid junction (left), concrete base plate (right)

The following chart, **(Table 1)**, provides an overview of the textile meshes, and the following images show the materials in detail and their installation into the specimen.

Table 1: Properties of the Textiles

Textile	Material / Structur	Coating	Mesh width 0° / 90°	Rovings per rm 0° / 90°
1	Carbon / 2D	SBR	14 mm / 8 mm	125 / 71
2	Carbon / 2D	EP	20 mm / 20 mm	50 / 50
3	Carbon / 3D	SBR	15 mm / 15 mm	56 / 93
4	Carbon / 2D	SBR	14 mm / 13 mm	59 / 59

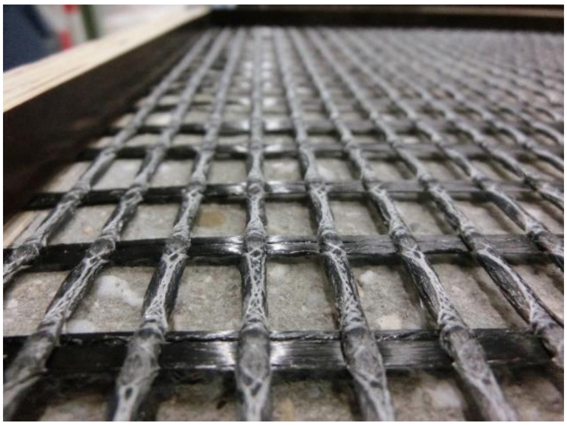

Figure 4: Textile 1

Figure 5: Textile 2

Figure 6: Textile 3

Figure 7: Textile 4

After the Textile anodes were applied to the concrete base, the test specimens were cast with the special mortar. This embedded layer had a depth of 15 mm and formed finely to the surface of the test specimens (see Figure 2). Three different mortars were tested, so that in combination with the four anode materials it totaled 12 specimens. The following chart, **(Table 2)**, gives an overview of the mortar properties:

Table 2: Overview of the mortar properties

Mixture	Mortar mixture	Water	Water-reducing admixture 1	Water-reducing admixture 2	Additive	Pressure resistance [N/mm²]	Density [kg/dm³]
B	X	X	X		X	110.3	2.37
C	X	X				77.6	2.26
D	X	X		X	X	118.2	2.40

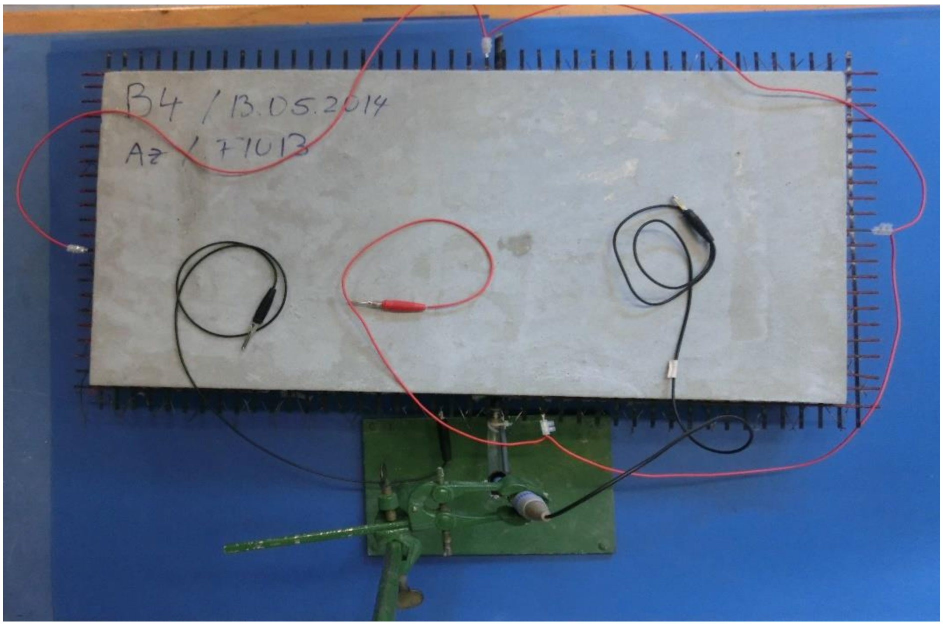

Figure 8: complete test specimen

When the specimens were developed, they were connected to the Potentiostat. The carbon textiles act as a working electrode, while the MMO was connected as a counter electrode (see Fig. 8). Following galvanostatic stages, experiments were carried out. Here, the voltages of the working electrode were measured against the reference electrode. The reference electrode was silver-silver chloride electrode, which was inserted into a tube that was provided for this purpose and connected to the solution over the electrolyte bridge. At a predetermined interval, the current densities were kept constant before they gradually increased and then the process is repeated. The current densities increased with each step and, in detail, were 0 $\frac{mA}{m^2}$ (open circuit potential); 1 $\frac{mA}{m^2}$; 3.2 $\frac{mA}{m^2}$; 10 $\frac{mA}{m^2}$ und 20 $\frac{mA}{m^2}$.
Following each stage, instant-off measurements were performed. This procedure ensured that IR drop liberated potentials were measured, and that the actual polarization of the anode material is not overrated. Following the last instant-off measurements, a depolarization's measurement has been carried out. For this purpose, the current was not previously kept as constant, but it has been turned off. The duration of the intervals were chosen sufficiently large (12 h), so that the recorded potentials begin to approach a limit where almost no changes were detected.

4. Results

Figure 9 shows an exemplary curve of the galvanostatic stages experiment of the specimen B1. The four stages in the various current densities can be clearly seen, and that the potential values arrived after 12-hour depolarization's measurement approximately at a constant level. After 36 hours, the galvanostatic measurement is completed with 10 mA. The IR drop can also be seen in the graph.

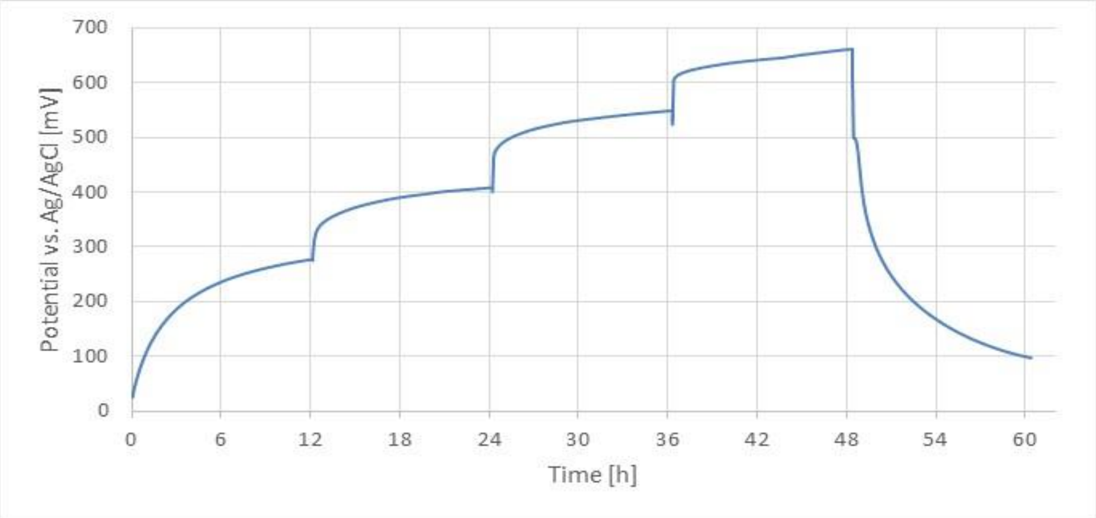

Figure 9: Galvanostatic test by progressive current densities – specimen B1

To evaluate the galvanostatic stage testing with relation to the CP, current density-potential curves were generated, as the following four figures show. The curves of the different embedding mortars are shown for each textile and show which mortar is most suitable for each. All the polarization curves were shifted to the origin so the polarization of the various textiles can be compared. It can be seen, from the comparison of the curves, which mortar with which carbon textile has the lowest voltage required to achieve the 10 mA/m².

On the basis of the measurements for textile 1, show mortar B is the most appropriate. In textile 3 and 4, mortars B and D have almost identical results. In textile 4, the difference of polarization of textiles in mortars C, B, and D is still less than 100 mV, and these in textile 3 is several hundred millivolts. The significantly deviating course of the measurement curves of textile 2 can be explained due to the epoxy coating. This represents an increased resistance compared to Styrene-butadiene (SBR) coating, so the conductivity of the material decreases.

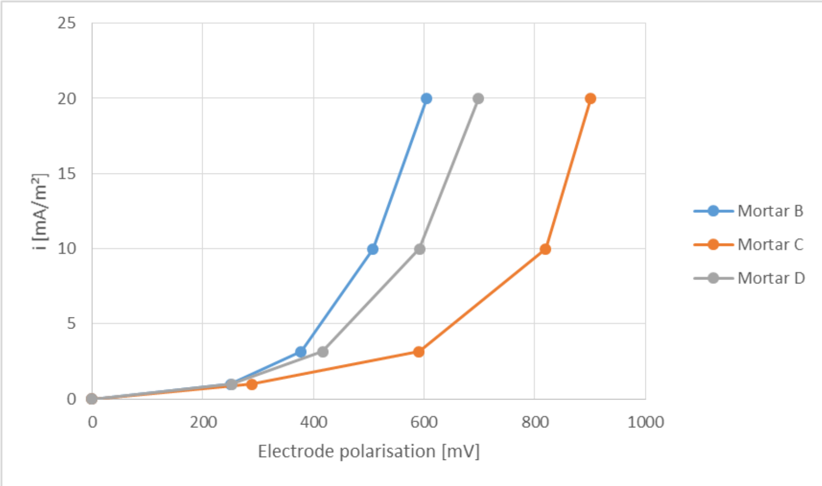

Figure 10: Current density-potential-Curve Textile 1

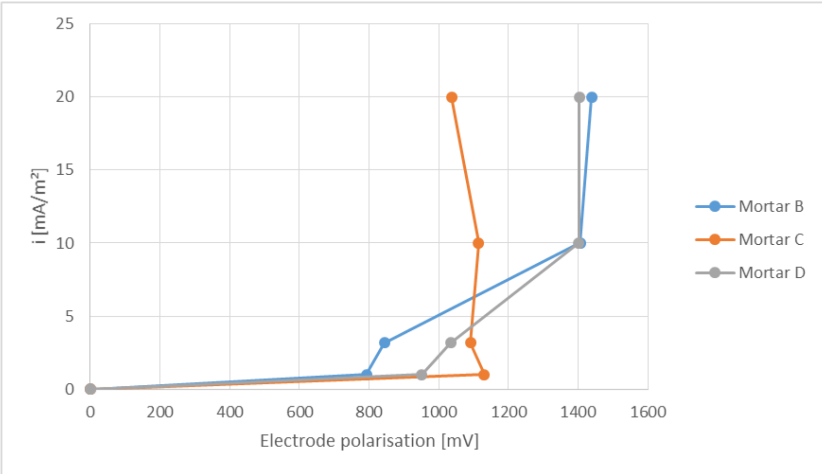

Figure 11: Current density-potential-Curve Textile 2

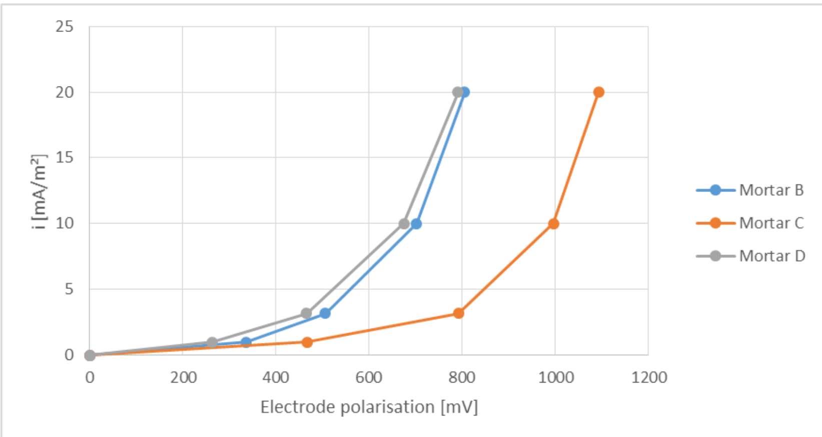

Figure 12: Current density-potential-Curve Textile 3

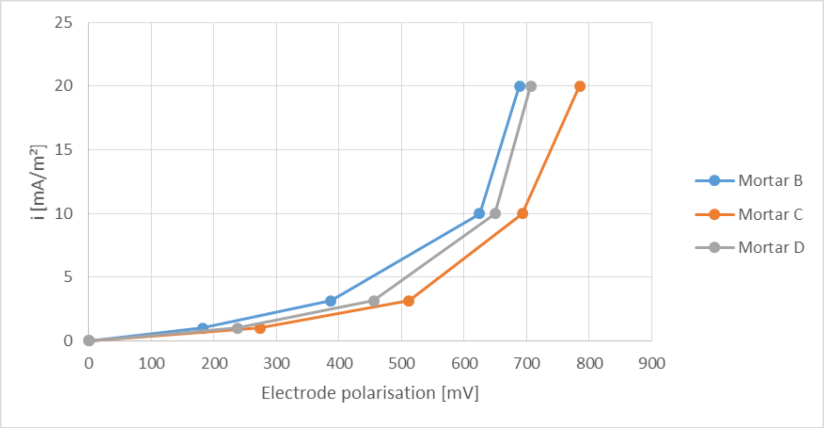

Figure 13: Current density-potential-Curve Textile 4

The evaluation, with respect to the three tested mortar mixtures, has shown that mortars B and D, with each textile, have almost identical polarization properties. Accordingly, they have the lowest voltages needed to achieve the protection current density.

The lowest values in absolute terms are among the systems B1 and B4 and D4.

In this work, these combinations were favored for further investigation. Benefits can result due to the different properties of the anode materials in practice. While textile 1 is on rolls, the textile 4 is supplied in mats. It could, thus, be decided during installation depending on local characteristics.

5. Conclusions

Measurements have shown that the impregnation of the textiles has a considerable influence on the polarizability of carbon textiles. The SBR-impregnated materials revealed a significantly better electrical conductivity compared to the EP-impregnated textiles. Furthermore, the 3D structure of the textile type 3 has been found to not be as advantageous compared to the 2D structures of the textile types 1 and 4. These two materials achieved opposite values in the experimental measurements. Therefore, they were considered particularly useful in the selection of the four tested materials for the CCP. Upon evaluation of the performance of the tested mortars, it turned out that the mortar mixture B is most suitable for use in the CCP. But all investigated mortars can be used as embedding material for CCP. In conclusion, carbon textiles are suitable as an anode material for the CCP.

6. References

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