



ANALYZING OF COATINGS ON STEEL - REINFORCED CONCRETE ELEMENTS BY MOBILE NMR

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A large number of infrastructural concrete buildings are protected against aggressive environments by coating systems. The functionality of these coating systems is mainly affected by the composition and thickness of the individual polymeric layers. For the first time ever, a mobile nuclear magnetic resonance (NMR) sensor allows a non-destructive determination of these important parameters on the building site. However, before this technique can be used on steel-reinforced concrete elements, the potential effect of the reinforcement on the measurement, i.e. the NMR signal, needs to be studied. The results show a shift of the NMR profile as well as an increase of the signals amplitude in the case of the reinforced samples, while calculating the thickness of concrete coating leading to identical results.

Keywords: Coating, Concrete, Non-destructive Testing, NMR, Layer Thickness

1. INTRODUCTION

The use of coating systems on infrastructural concrete buildings as protection against aggressive environments has increased in the last ten years. The main aims which can be realized with these coating systems are:

- Prevent the ingress of potentially aggressive substances such as water, chloride, and/or carbon dioxide, which are frequently found in the surrounding of infrastructural concrete buildings.
- Reducing the water content of the concrete due to evaporation of water through the coating.
- Increasing the resistance against chemical and/or mechanical attack such as e.g.: sulphur dioxide found in wastewater plants or abrasion by car tires on concrete surfaces.

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The concrete coatings usually consist of individual layers of polymers or cement-based materials. Concrete coatings are also called “surface protection systems” in Germany. To ensure the target functions of a surface protection system, the following aspects are important: Thickness of the individual coating layers, application method of the coating materials, consideration of environmental parameters such as temperature, humidity, and wind as well as preparation of the substrate. The last three points affect the reactive hardening of the coating materials which is directly linked to the material properties and the adhesion between concrete and coating as well as between the individual layers. The thickness of the coating layers mainly affects the durability and properties such as the crack bridging of the surface protection system. Until now, there are no non-destructive test-methods to determine:

- The total thickness of the surface protection system as well as the thickness of the individual layers,
- the water transport through the surface protection system,
- the drying process of the concrete after application of a surface protection system,
- changes to the material due to weathering,
- quality and conformity of the applied material.

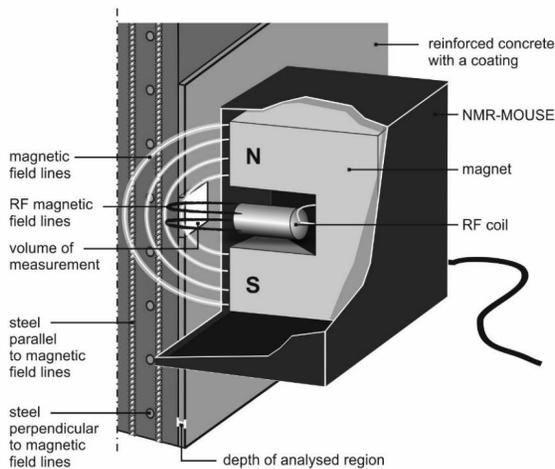


Fig. 1. Application of the NMR MOUSE on buildings. The device senses the composition of the substrate at the point where the magnetic field lines of the magnet and of the RF coil cross each other.

Operators place the device at different distances from the surface to analyze slices at different depths.

Modified drawing according to [1]

The NMR MOUSE[®] (Mobile Universal Surface Explorer, registered trademark of RWTH Aachen University) was recently found to exhibit a great potential for investigating these issues in a non-destructive way [2], [3], [4]. However, before the mobile NMR can be applied at construction sites as drawn in Fig. 1, the potential influence of steel reinforcements on the NMR signal has to be investigated. A parameter study on this influence will be the main focus of this paper. In addition, measuring the layer thickness of a multi-layer concrete coating is presented.

2. THE USED INVESTIGATION METHOD WITH THE NMR MOUSE

Nuclear magnetic resonance (NMR) is a method to assess molecular properties by stimulating a response of the atomic nuclei using magnetic fields and radio-frequency irradiation. In contrast to conventional NMR spectroscopy, which uses highly homogeneous magnetic fields, the method used here relies on inhomogeneous magnetic fields applied from a single side [5], [6], [7]. The advantage of single-sided NMR is the virtually unlimited sample size as well as the potential to construct mobile devices that can eventually be used on construction sites. Similar devices have been used in the oil industry (well logging) [8], food industry [9] and for the characterisation of natural stones [10]. A compact unilateral sensor developed for non-destructive testing of materials containing hydrogen atoms, the so-called NMR MOUSE was used for the described work [6]. Different types of the NMR MOUSE are available. The types differ in terms of frequency, gradient, measuring depth, and resolution [11]. For the investigations described in this paper, the NMR MOUSE PM 5 with a resonance frequency of 18 MHz was used. The PM 5 has a measuring field of 20 by 20 mm in the cross-section and the thickness can be chosen between 10 and 100 μm (volume of measurement = sensitive volume). The NMR signal is collected in the described sensitive volume which can be moved up to 5 mm deep into the specimen by using a stepper-motor driven, high-precision automatic lift which changes the distance between the sensor and the sample. The NMR sensor is mounted on this lift by means of a mobile plate while the specimen is placed on a fixed top plate which is parallel to the mobile plate (Fig. 2). The most important parameters determined by the NMR MOUSE are the signal amplitude which is indicative for the number of protons in the sensitive volume and the transverse relaxation time T2 which relates to the molecular mobility. This information is obtained by using the Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence and analysing the resulting spin echos [5]. In order to assess the number of protons, the first 5 to 10 spin echoes were integrated. The depth profiles shown in the results section were constructed by plotting these values versus the measuring depth.

To determine the transverse relaxation time T_2 , the decay of the echo amplitudes is fitted using an exponential function (Fig. 3) with the type of exponential function depending on the material [12].

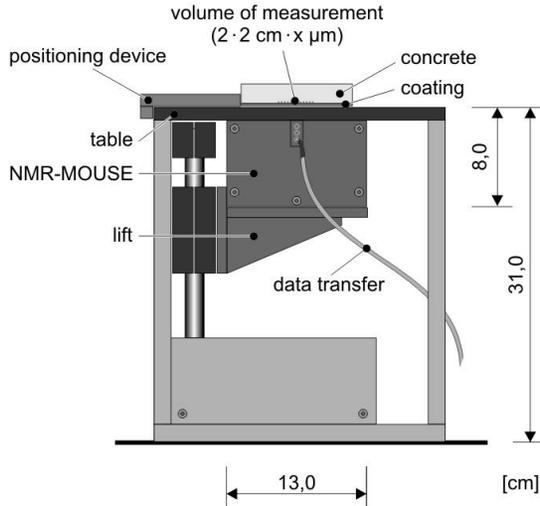


Fig. 2. Schematic of the lift used to reposition the volume of measurement inside the sample. The sample is placed on the top plate, which is parallel to the mobile plate on which the sensor is mounted

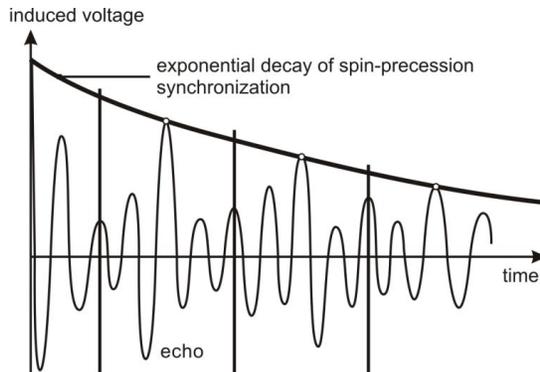


Fig. 3. Due to the inhomogeneous magnetic field of the NMR MOUSE, the generation of a T_2 signal response requires multiple RF pulses that create signals known as echoes. The amplitudes of the echoes can then be assembled into a useful T_2 signal. The integration of the first few echoes provides values which relates to the number of protons

3. DESCRIPTION OF THE INVESTIGATIONS

In order to realize an investigation with a wide variation of parameters, a simplified test method had to be developed without using coated, steel-reinforced concrete plates. For that, sandwich elements with a total thickness of approx. 3 mm consisting of a 2.6 wt-% copper sulphate solution or polyurethane film embedded between two glass plates were produced. In the following, the first ones will be referred to as g-c-g elements. Copper sulphate was chosen because the paramagnetic nature of Cu^{2+} shortens the relaxation time compared to water which leads to an acceleration of the measurements, while polyurethane represents a typical coating material. Secondly, a rectangular polyethylene framework was built having 48 bore holes to host the steel bars. Sandwich element and box were mounted on the table of the NMR lift as shown in Fig. 4. Table 1 provides an overview of the parameters studied. The thickness of the concrete cover is represented by the distance of the steel bars to the measuring table minus the thickness of the sandwich elements. The distance between two steel bars was varied by using the different bore holes, but the sensitive volume always remained in the centre (Fig. 4). In most cases two steel bars were positioned parallel to each other, which were oriented perpendicular (90°) or parallel (0°) to the magnetic field lines (Fig. 1). In order to model a reinforcement mesh, 4 steel bars were used in a square arrangement. Stainless as well as ordinary structural steel was tested.

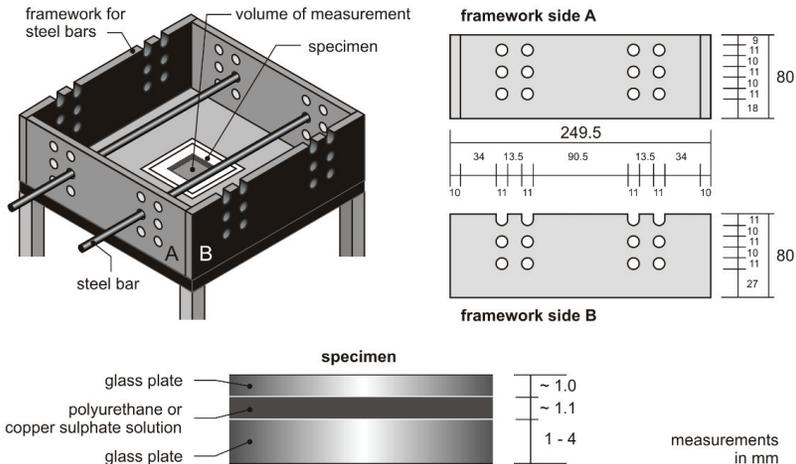


Fig. 4. Experimental setup used to investigate the influence of steel reinforcements on the NMR-signal. The specimen shown on the bottom represents the coating while the framework including the steel bars substitute the steel-reinforced concrete

To check whether the calculated amount of protons in the sensitive volume depends on the position of the sensitive volume inside the sample, the thickness of the lower glass plate of the sandwich element was varied between 1 and 4 mm. Choosing a lower glass plate of 4 mm results in a maximum measuring depth of 5 mm for the copper sulphate solution which reduces the distance between steel and sensitive volume by approx. 5 mm.

Table 1. Overview of the studied parameters

Parameter	Unit	Variation						
Approx. distance between steel bars and measuring table	cm	2	3	4	5	6	7	
Diameter of steel bars	mm		6		8		10	
Approx. distance between two steel bars	cm		10		12.5		15	
Number of steel bars	-		2				4	
Type of steel	-		Stainless				Structural	
Orientation of steel bars to the magnetic field	°		0				90	
Thickness of lower glass plate	mm		1		2		3	4
Substance inside sandwich element	-		Copper sulphate solution				Polyurethane	

For all measurements, the thickness of the sensitive volume was chosen similar to the step size of 50 μm while using an echo time of 0.049 ms and a recycle delay of 0.3 s. With this step size, the amount of protons at different depths inside the specimen was calculated and plotted in the form of a depth profile. Analysing this profile allows to assess the influence of the steel bars on the amplitude and the profile shift as well as the material thickness. To underline the power of the NMR MOUSE concerning the non-destructive investigation of polymer coatings on concrete elements an example of thickness measurement will be given at the end of the paper. Fig. 5 illustrates the configuration of the investigated coating system. The given layer thicknesses has been determined with an optical microscope on the cross-section of the specimens.

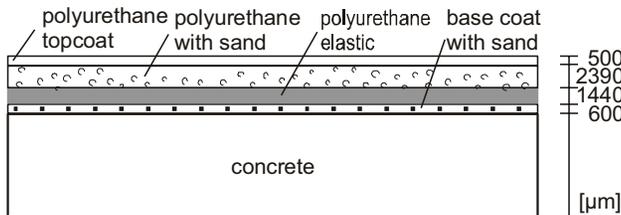


Fig. 5. Composition of the multilayer coating (Abbr.: B)

4. RESULTS AND DISCUSSION

4.1. INFLUENCE OF STEEL REINFORCEMENT - RESULTS

Fig. 6 shows two depth profiles which were recorded using the test setup illustrated in Fig. 4. In the first example, no steel reinforcement was present above the g-c-g element, while in the second one, two reinforcement bars with a diameter of 8 mm and a spacing of 10 cm were arranged 2 cm above the sandwich element with an orientation of 90° to the magnetic field lines. Since there are only very few hydrogen atoms in the glass plates, a signal can only be recorded within the aqueous copper sulphate solution. To extract the layer thickness of the copper sulphate solution, the measuring depths corresponding to the “half height”, i.e. half of the mean maximum amplitude on the ascending and descending branches was determined. The layer thickness is then given by the distance between these two points. From 30 measurements with the given measuring parameters, an average deviation of $2.5 \mu\text{m}$ resulted for the calculated layer thickness. To reduce the measuring time, all following measurements were performed as single determination.

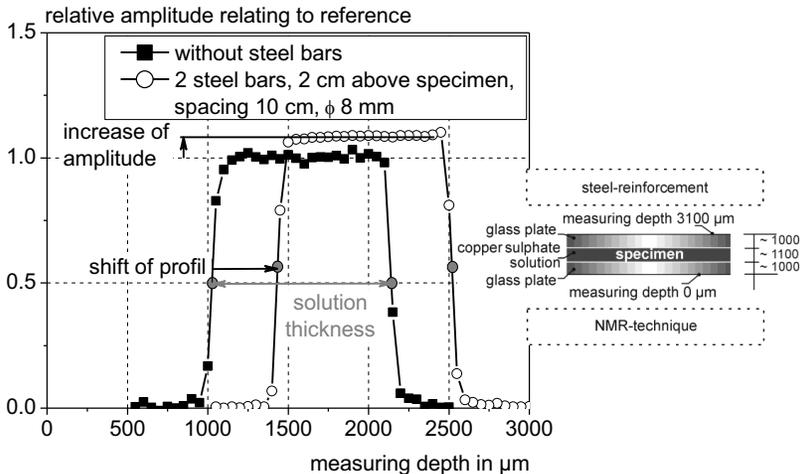


Fig. 6. Depth profiles for the g-c-g element as determined by the NMR MOUSE.

The measuring depth of $0 \mu\text{m}$ is located at the borderline between NMR sensor and lower glass plate as illustrated on the right. Since hydrogen atoms are only found in the aqueous copper sulphate solution, a signal is only obtained in this area

The points used to calculate the thickness of the copper sulphate solution also allow calculating the displacement of the sensitive volume (profile shift) originating in the presence of the steel bars. The attraction of the steel causes a shift in the magnetic field of the NMR MOUSE towards the steel. Thus, the position of the sensitive volume is shifted to larger measuring depths by about 400 μm . Moreover, the magnetic field experiences a homogenization by the steel. The resulting decrease of the gradient causes an increase of the volume activated in the specimen which results in an increase of the amplitude. Fig. 7 shows this effect as function of the diameter of the steel bars. For the measurements, two steel bars with a spacing of 10 cm and an orientation of 90° to the magnetic field lines were arranged at different distances to the measuring table. The values are given as ratio of the signal intensities with and without steel. The larger the diameter, the higher the amount of steel (largest diameter 10 mm) and the larger the increase of the signal amplitude. The maximum increase is about 11 %. At a distance of 7 cm, the steel no longer exerts an influence on the amplitude regardless of the diameter. The standard deviation calculated out of 25 repetition measurements is given for the steel bars with a diameter of 8 mm and a distance between steel bars and measuring table of 2 cm, exemplarily. However, the measured layer thicknesses of the copper sulphate solution, was found not to be influenced by the presence of steel bars: The ratio of the layer thickness with and without steel is for all experiments approx 1. Fig. 8 illustrates the profile shift depending on the diameter of the steel bars and the distance to the measuring table. In this experiment, the orientation of the steel was kept constant at 90° to the magnetic field.

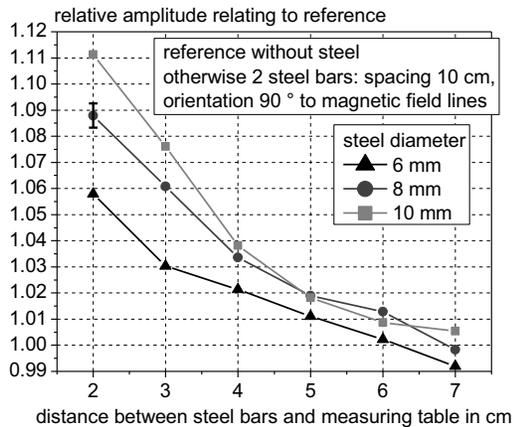


Fig. 7. Influence of the distance between steel bars and measuring table and the steel diameter on the relative amplitude relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and an orientation of 90° to the magnetic field lines

At a distance of 2 cm between steel and measuring table, the profile is shifted by slightly less than 500 μm because of two steel bars with a diameter of 10 mm, a spacing of 10 cm. The larger the distance between steel and measuring table (i. e., the thicker the concrete cover at the building), the smaller the profile shift towards the steel (reinforcement). The same applies to the amount of steel: the smaller the diameter of the steel bars, the smaller the profile shift. At distances > 4 cm, the diameter of the steel bars no longer exerts any significant influence. The type of steel (reinforcement steel or stainless steel) has no effect on the measurements. The shift of the profile towards the steel as well as the increase in the amplitude is in the same dimension for both steel types.

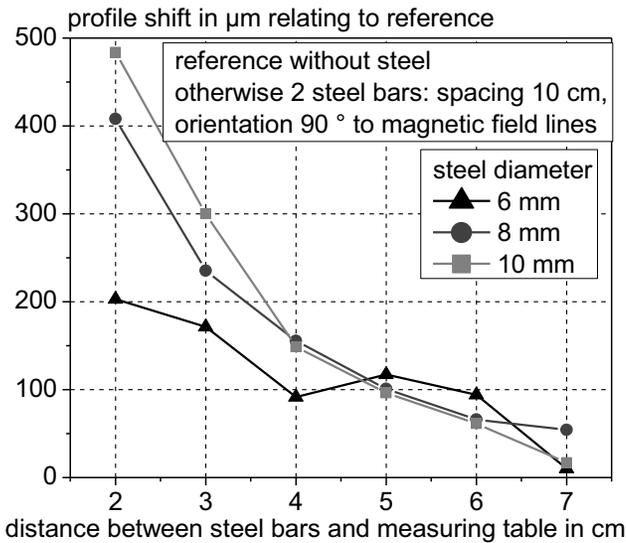


Fig. 8. Influence of the distance between steel bars and measuring table and the steel diameter on the profile shift in μm relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and an orientation of 90° to the magnetic field lines

The orientation of the steel bars to the magnetic field lines only exerts a significant effect on the profile shift at distances < 4 cm between steel and measuring table (Fig. 9). A distance between steel and measuring table of 2 cm and an angle of 90° between the long axis of the steel and the magnetic field lines causes an increase in the profile shift by approx. 150 μm as compared to the parallel orientation. With an increasing spacing between the steel bars, the profile shift decreases;

this also corresponds to a larger distance between steel and measuring field. When the distances between steel and measuring table are larger than 4 cm, this influence is, however, no longer relevant. At a steel diameter of 6 mm and a spacing of the steel bars of 15 cm (distance from the measuring field 6.5 cm, each), the distance between steel and measuring table has no longer any significant relevance. An increase in the amount of reinforcement from 2 to 4 steel bars causes an increase in the profile shift towards the steel. The 4 steel bars represent a section from a steel mesh with steel spacing of 10 and 15 cm, respectively. Further details are given in [13].

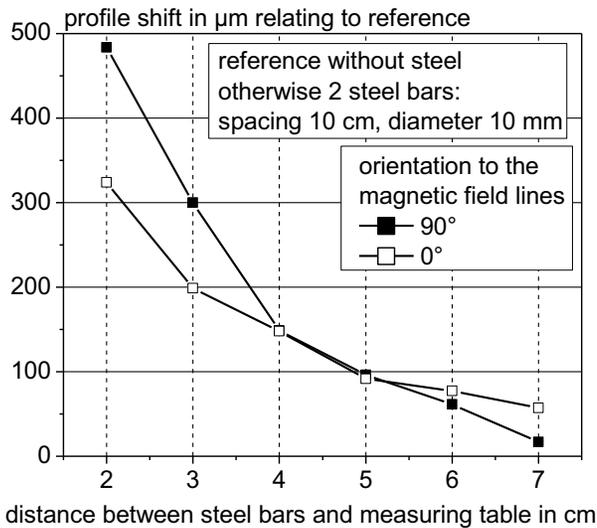


Fig. 9. Influence of the distance between steel bars and measuring table as well as the steel orientation on the profile shift in μm relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and a diameter of 10 mm

4.2. INFLUENCE OF STEEL REINFORCEMENT - DISCUSSION

The results illustrated before have shown that the existence of steel in the range of the measurements conducted with the NMR MOUSE has the following effects on the determination of depth profiles:

- shift of the profile towards the steel,
- increase in the measured amplitude,
- but unchanged layer thicknesses.

For measuring of the layer thicknesses of coatings on steel-reinforced concrete buildings, this means that the measured layer thickness is independent of the steel reinforcement. Only the position and the amplitude of the coating layers are influenced by the reinforcement in the concrete. To what extent the position and the amplitude of the coating layers are changed depends on the following parameters:

- concrete cover (the larger, the smaller the influence; at 7 cm only minimal influence),
- steel diameter (the larger, the larger the influence; decisive at concrete covers ≤ 4 cm),
- horizontal distance between the steel bars and from the measuring field (the larger, the smaller the influence; decisive at concrete covers ≤ 4 cm),
- amount of steel (the more, the higher the influence),
- orientation of the steel to the magnetic field (90° has a larger effect than 0° ; decisive at concrete covers < 4 cm).

The examination of the relative profile shift relative to the reference without steel is not target-oriented because of the different measuring depths. Hence, at a measuring depth of $2000 \mu\text{m}$ and a profile shift of $200 \mu\text{m}$, the relative shift by 10% would be lower than that in a measuring depth of $1000 \mu\text{m}$ (20%).

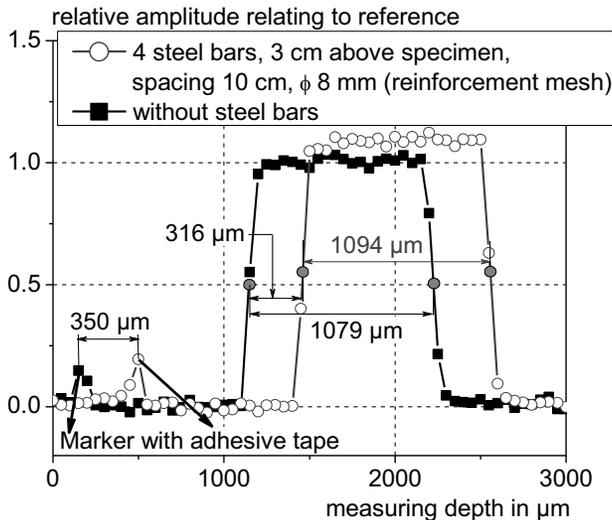


Fig. 10. Depth profiles for the g-c-g element determined by the NMR MOUSE using a marker.

Correction of the profile shift due to steel bars can be done by using the marker position

as designed measuring depth 0

There are two possibilities to consider the shift of the profile towards the steel while measuring the layer thicknesses of coatings on steel reinforced concretes. Firstly the profile shift could be corrected by a factor which is calculated from a model considering the influences described before.

By means of an in situ location of the steel (concrete cover, steel diameter, bar spacing) and the model, a correction of the building examinations can then be made. However, a simpler alternative to the model would be the application and measurement of a marker at the building.

The profile shift resulting from reinforcement can be taken into account at any measurement by means of the marker. As the layer thickness as such is not influenced by the reinforcement, a correction is not necessary in this place. A correction is also not required for the amplitude because this relative value always experiences the same shift independent of the coating material and because the absolute magnitude of the amplitude is not decisive when measuring the profile. Those cases, in which the absolute magnitude of the amplitude at varying steel reinforcement is relevant (e. g. water penetration front into a material) can, however, not be answered without the model. Nevertheless, this is not the subject of this paper.

Fig. 10 illustrates the simple and practical solution using the markers during a profile measurement. In [3] the transferability of these investigations to coated steel reinforced concrete specimens is demonstrated.

4.3. THICKNESS OF COATINGS

Fig. 11 shows a comparison of two coated concrete specimens with the same multilayer coating B – only the PUR top coat differs, marked with the number 2 or rather 3. The composition and layer thicknesses are described in Fig. 5. The thickness of the sensitive volume was 100 μm , the echo time was 0.038 ms and the recycle delay 0.3 s. The increasing polymer content leads to an increase in the amount of protons. This allows a differentiation of the top coating, the PUR-layer with sand, and the elastic coating.

Fig. 11 illustrates a lower thickness of the PUR elastic coating of specimen OS 11a_3 compared to specimen OS 11a_2. The thickness of this layer is reduced from $\sim 2000 \mu\text{m}$ to $\sim 1500 \mu\text{m}$. The thickness of the wearing layer of OS 11a_3 is also reduced in comparison to OS 11a_2. Furthermore, the different materials for the top coat can be distinguished by the changed amount of protons in this area. The use of the same materials for the base, elastic, and wearing coat is also detectable by the unchanged proton density. Consequently, the NMR MOUSE can be used as quality control for the uniformity of coatings on the construction site.

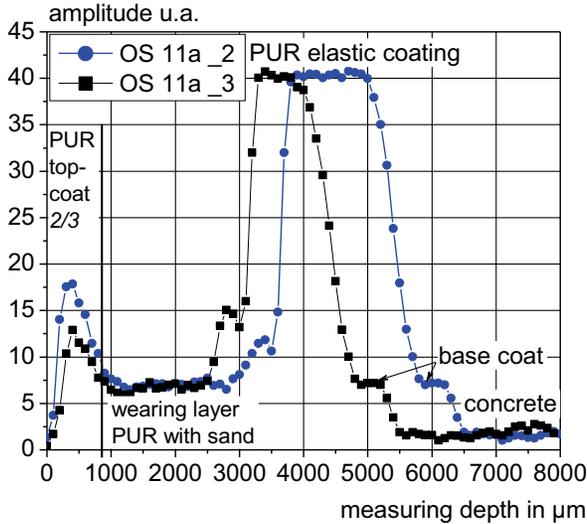


Fig. 11. NMR MOUSE depth profiles of two specimens with the same multilayer coating on concrete (exception: the modified top-coat). The 5 mm depth profiles were measured from both sides of the specimen and combined to archive a measuring depth of 8 mm

CONCLUSIONS

For the destruction-free examination of the composition and the layer thicknesses of coatings on steel reinforced concrete buildings with the mobile NMR technology, the effect of the steel reinforcement on the results must be taken into account. Within the framework of this paper it was shown that the measured depth profile is shifted depending on the amount and the position of the steel reinforcement in the concrete whereas the amplitude increases. The measured layer's thicknesses, however, is not influenced by the reinforcement.

A method which is also applicable on site was presented in order to measure and to correct the profile shift due to reinforcement: A marker placed on the coating surface serves as mathematical zero point to which the further profile is related. Finally, the scope of possible applications of the mobile NMR MOUSE for layer thickness measurements of coatings on concrete buildings was described. The individual layer of complexly structured coating systems can be analysed.

ACKNOWLEDGMENT

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The continuance of the study take place at the department of building materials at the technical university in Dortmund.

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Fig. 1. Application of the NMR MOUSE on buildings. The device senses the composition of the substrate at the point where the magnetic field lines of the magnet and of the RF coil cross each other. Operators place the device at different distances from the surface to analyze slices at different depths. Modified drawing according to [3].

Rys. 1. Zastosowanie NMR MOUSE w budynkach. Urządzenie wykrywa skład podłoża w miejscu, gdzie przecinają się linie pola magnetycznego magnesu oraz cewki RF. Operatorzy umieszczają urządzenie w różnych odległościach od powierzchni, aby analizować plastry na różnych głębokościach. Rysunek zmodyfikowany według [3].

Fig. 2. Schematic of the lift used to reposition the volume of measurement inside the sample. The sample is placed on the top plate, which is parallel to the mobile plate on which the sensor is mounted.

Rys. 2. Schemat podnośnika wykorzystywanego do przeniesienia wielkości pomiaru wewnątrz próbki. Próbka umieszczona jest na górnej płycie, która jest równoległa do płyty ruchomej, na której zamontowany jest czujnik.

Fig. 3. Due to the inhomogeneous magnetic field of the NMR MOUSE, the generation of a T2 signal response requires multiple RF pulses that create signals known as echoes. The amplitudes of the echoes can then be assembled into a useful T2 signal. The integration of the first few echoes provides values which relates to the number of protons.

Rys. 3. Ze względu na niejednorodne pole magnetyczne NMR MOUSE, generowanie odpowiedzi sygnału T2 wymaga wielokrotnych impulsów RF, co tworzy sygnały znane jako echa. Amplitudy echa mogą następnie zostać złożone w przydatny sygnał T2. Integracja pierwszych kilku sygnałów echa dostarcza wartości, które odnoszą się do liczby protonów.

Fig. 4. Experimental setup used to investigate the influence of steel reinforcements on the NMR-signal. The specimen shown on the bottom represents the coating while the framework including the steel bars substitute the steel-reinforced concrete.

Rys. 4. Ustawienie eksperymentalne w celu zbadania wpływu zbrojenia stalowego na sygnał NMR. Próbka pokazana na dole pokazuje powłoki, podczas gdy ramy, w tym stalowe pręty, stanowią beton zbrojony.

Fig. 5. Composition of the multilayer coating (Abbr.: B).

Rys. 5. Skład wielowarstwowej powłoki (skrót: B).

Fig. 6. Depth profiles for the g-c-g element as determined by the NMR MOUSE. The measuring depth of 0 μm is located at the borderline between NMR sensor and lower glass plate as illustrated on the right. Since hydrogen atoms are only found in the aqueous copper sulphate solution, a signal is only obtained in this area.

Rys. 6. Profile głębokości elementu g-c-g, ustalone przez NMR MOUSE. Głębokość pomiarowa 0 μm znajduje się na granicy pomiędzy czujnikiem NRM a niższą płytą szklaną, jak pokazano po prawej stronie. Jako że atomy wodoru znajdują się jedynie w wodnym roztworze siarczynu miedzi, sygnał może być uzyskany jedynie w tym obszarze.

Fig. 7. Influence of the distance between steel bars and measuring table and the steel diameter on the relative amplitude relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and an orientation of 90° to the magnetic field lines.

Rys. 7. Wpływ odległości między prętami stalowymi, stołem pomiarowym i średnicą stali na amplitudę względną względem odniesienia bez stali. Parametry stałe: 2 stalowe pręty z odstępem 10 cm i orientacją 90° do linii pola magnetycznego.

Fig. 8. Influence of the distance between steel bars and measuring table and the steel diameter on the profile shift in μm relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and an orientation of 90° to the magnetic field lines.

Rys. 8. Wpływ odległości między prętami stalowymi, stołem pomiarowym i średnicą stali na przemieszczenie profilu w μm względem odniesienia bez stali. Parametry stałe: 2 stalowe pręty z odstępem 10 cm i orientacją 90° do linii pola magnetycznego.

Fig. 9. Influence of the distance between steel bars and measuring table as well as the steel orientation on the profile shift in μm relative to the reference without steel. Constant parameters: 2 steel bars with a spacing of 10 cm and a diameter of 10 mm.

Rys. 9. Wpływ odległości między prętami stalowymi i stołem pomiarowym, jak i orientacja stali na przemieszczeniu profilu w μm względem odniesienia bez stali. Parametry stałe: 2 stalowe pręty z odstępem 10 cm i o średnicy 10 mm.

Fig. 10. Depth profiles for the g-c-g element determined by the NMR MOUSE using a marker. Correction of the profile shift due to steel bars can be done by using the marker position as designed measuring depth 0.

Rys. 10. Profile głębokości elementu g-c-g, ustalone przez NMR MOUSE, przy pomocy znacznika. Korekcję na przemieszczenie profilu, ze względu na stalowe pręty, można uzyskać przez wykorzystanie pozycji znacznika jako zaprojektowanej głębokości pomiarowej 0.

Fig. 11. NMR MOUSE depth profiles of two specimens with the same multilayer coating on concrete (exception: the modified top-coat). The 5 mm depth profiles were measured from both sides of the specimen and combined to archive a measuring depth of 8 mm.

Rys. 11. Profile głębokości NMR MOUSE dwóch próbek z tą samą, wielowarstwową powłoką na betonie (wyjątek: zmodyfikowana powłoka nawierzchniowa). Głębokie na 5 mm profile zostały zmierzone z obu stron próbki i połączone, aby zarchiwizować głębokość pomiarową 8 mm.

Table 1. Overview of the studied parameters.

Tabela 1. Przegląd badanych parametrów.

ANALIZA POWŁOK ELEMENTÓW BETONOWYCH ZBROJONYCH STALĄ PRZY ZASTOSOWANIU MOBILNEGO URZĄDZENIA NMR

Słowa kluczowe: powłoka, beton, badania nieniszczące, NMR, grubość warstwy

STRESZCZENIE:

Duża ilość infrastrukturalnych budynków betonowych, przed agresywnym środowiskiem, zabezpieczona jest systemami powłok. Na funkcjonalność tych systemów wpływ mają głównie skład oraz grubość poszczególnych warstw polimerowych. Po raz pierwszy w historii czujnik mobilnego magnetycznego rezonansu jądrowego (NMR) pozwala na nieniszczące ustalenie:

- całkowitej grubości systemu ochrony powierzchniowej, jak i grubości poszczególnych warstw,
- przepływu wody przez system ochrony powierzchni,
- procesu suszenia betonu po zastosowaniu systemu ochrony powierzchni,
- zmiany materiału ze względu na wietrzenie,
- jakości i zgodności zastosowanego materiału na placu budowy.

W przypadku NMR MOUSE® (Mobilny Uniwersalny Eksplorator Powierzchni, zarejestrowany znak towarowy RWTH Uniwersytetu Aachen) stwierdzono niedawno wielki potencjał w badaniu problemów w sposób nieniszczący. Jednakże, zanim można zastosować NMR na placu budowy, jak na Rys. 1., należy zbadać potencjalny wpływ stalowego zbrojenia na sygnał NMR. Badanie parametrów tego wpływu jest głównym tematem niniejszej pracy. Dodatkowo zaprezentowane zostały pomiary grubości warstw wielowarstwowej powłoki betonowej.

Wyniki przedstawione w pracy pokazują, że obecność stali w zakresie pomiarów przeprowadzanych NMR MOUSE ma następujący wpływ na ustalenie głębokości profilu:

- przesunięcie profilu do stali,
- zwiększenie mierzonej amplitudy,
- ale niezmienną grubość warstw.

W przypadku mierzenia grubości warstw powłoki na zbrojonych stalą budynkach betonowych oznacza to, że grubość warstw jest niezależna od zbrojenia stalowego. Jedynie pozycja i amplituda warstw powłoki są pod wpływem zbrojenia w betonie.

Zakres w jakim zmienione zostaną pozycja i amplituda warstw powłok zależy od poniższych parametrów:

- otuliny betonu (im większa, tym mniejszy wpływ; przy 7 cm jedynie minimalny wpływ),
- średnicy stali (im większa, tym większy wpływ; decydująca przy otulinach betonu ≤ 4 cm),
- poziomej odległości pomiędzy prętami stalowymi i od obszaru pomiarowego (im większa, tym mniejszy wpływ; decydujące przy otulinach betonu ≤ 4 cm),
- ilości stali (im więcej, tym większy wpływ),
- orientacji stali względem pola magnetycznego (90° ma większy wpływ niż 0° , decydujące przy otulinach betonu < 4 cm).

Badanie względnego przemieszczenia profilu w stosunku do odniesienia bez stali nie jest ukierunkowane, ze względu na różne głębokości pomiarowe. Dlatego też, głębokość pomiarowa 2000 μm oraz przemieszczenie profilu 200 μm , względne przemieszczenie o 10% byłoby niższe niż przy głębokości pomiarowej 1000 μm (20%).

Są dwie możliwości rozważenia kwestii przemieszczenia profilu w stronę stali w trakcie pomiarów grubości warstw powłok na betonie zbrojonym. Przede wszystkim przemieszczenie profilu powinno być skorygowane przez współczynnik, który obliczany jest z modelu biorącego pod uwagę wpływy opisane wcześniej. Poprzez lokalizację stali na budowie (pokrywa betonowa, średnica stali, odstępy między prętami) oraz model, można dokonać korekty badań budynku. Jednakże, łatwiejszą alternatywą dla modelu byłoby zastosowanie i pomiar znacznika na budynku. Przemieszczenie profilu wynikające ze zbrojenia można wziąć pod uwagę, przy każdym pomiarze, za pomocą znacznika.

Jako że grubość warstw sama w sobie nie jest pod wpływem zbrojenia, korekta nie jest wymagana w tym miejscu. Korekta również nie jest wymagana dla amplitudy, ponieważ ta wartość względna zawsze doświadcza tych samych przemieszczeń, niezależnie od materiału powłoki i ponieważ wielkość bezwzględna amplitudy nie jest decydująca przy mierzeniu profilu. Na te przypadki, w których bezwzględna wielkość amplitudy przy różnym zbrojeniu stalowym jest istotna (np. penetracja wody do materiału), nie można odpowiedzieć bez modelu. Niemniej jednak, to nie jest przedmiotem niniejszej pracy. Rys. 10 pokazuje proste i praktyczne rozwiązanie wykorzystania znaczników podczas pomiarów profilu. [13] pokazuje możliwość przenoszenia tych badań na próbki zbrojonego betonu powlekanego.

Rys. 11 pokazuje porównanie dwóch powlekanych próbek betonowych, z tą samą wielowarstwową powłoką B - jedynie różnią się nawierzchniową powłoką PUR, oznaczone numerem 2 lub raczej 3. Skład oraz grubość warstw jest opisana na Rys. 5. Zwiększająca się zawartość polimerów prowadzi do zwiększenia się protonów. To pozwala na zróżnicowanie górnej powłoki, warstwy PUR z piaskiem oraz powłoki elastycznej. Rys. 11 pokazuje niższą grubość poliuretanowej powłoki elastycznej, próbki OS 11a_3, w porównaniu do próbki OS 11a_2. Grubość warstwy zmniejszona jest z ~2000 μm do ~1500 μm . Grubość warstwy ścieralnej OS 11a_3 jest również zmniejszona, w porównaniu do OS 11a_2. Co więcej, rozróżnić można różne materiały w powłoce nawierzchniowej, dzięki zmienionej liczbie protonów w tym obszarze. Wykorzystanie tych samych materiałów do powłok bazowej, elastycznej oraz ścieralnej również można wykryć, dzięki niezmięnionej gęstości protonowej. W konsekwencji NMR MOUSE może być wykorzystywany do kontroli jakości w kwestii jednorodności powłok na budowie.

Wpływ zbrojenia stalowego na wyniki musi być wzięty pod uwagę podczas nieniszczących badań składu i grubości warstw powłok na zbrojonych budynkach betonowych technologią mobilnego NMR. W ramach niniejszej pracy wykazano, że mierzony profil głębokości jest przesuwany w zależności od ilości oraz pozycji zbrojenia stalowego w betonie, natomiast amplituda się zwiększa. Jednakże, mierzona grubość warstw nie jest zakłócana przez zbrojenie.

Metoda, którą również można zastosować na budowie została zaprezentowana, aby mierzyć i skorygować przesunięcie profili, ze względu na zbrojenie: Znacznik umieszczony na powierzchni powłoki służy jako matematyczny punkt zero, do którego kolejne profile są powiązane. Ostatecznie opisany został zakres możliwych zastosowań mobilnego NMR MOUSE do pomiarów powłok w budynkach betonowych. Analizowane mogą być pojedyncze powłoki kompleksowych struktur systemów powłok.