BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF CHEMICAL AND BIOENGINEERING
GEORGE OLAH DOCTORAL SCHOOL

PREPARATION AND APPLICATION OF CORE-SHELL AND SOLID MATRIX STRUCTURE MICROCAPSULES IN SELF-HEALING AND ANTI-FOULING COATINGS

PhD Thesis

Author: **Tamás Szabó**
Supervisor: **Dr. Judit Telegdi**
Consultant: **Dr. Erika Fekete**

MTA TTK
Institute of Materials and Environmental Chemistry,
Functional Interfaces Research Group

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I. Introduction

Paint coatings on metal surfaces are commonly used with the objective of isolating them from moisture, oxygen or general corrosive environment. They mostly form a passive barrier layer which protects the metal substrate, while intact. Following a scratch the corrosion can spread quickly, even under the intact coating.

Microorganisms are general threat to the structural materials. They settle on the surfaces in the surrounding wet medium, forming biofilms on them. This can be detrimental to the coated material, through phenomenon also known as microbiologically induced corrosion. This is a corrosion influenced by the microbial metabolites.

Possible solution to these problems is a special paint additive: micrometer diameter range spherical microcapsules, containing a corrosion inhibitor or anti-fouling ingredient. These carriers allow the trigger-controlled release of the active material stored inside them, e.g. in case of a mechanical damage or under constant circumstances, like wet conditions, they can provide a continuous, sustained release of a protecting material, restoring or elongating the efficacy of the coating.

II. Scientific background

Self-healing coatings

In recent years, among the functional polymers prominent place is taken by the ***self-healing coatings***. During the self-healing of damaged coating material a 'glue-like' substance activates upon mechanical stress or scratching to regenerate the coating, which is stored in the untouched paint matrix, in capsules. When the coating is damaged, the capsules break and the stored liquid from the inside leaks out along the scratch. If this liquid is a reactive material, it will solidify, forming a hardened protective layer between the metal surface and the environment.

Among encapsulated ***self-healing materials*** as additives are the vegetable, air-drying oils that in presence of air, during their oxidative polymerization they form a solid film. In the literature there are one preferred vegetable oil, the ***economical and environment-friendly linseed oil***[1,2,3,4,5].

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[1] Suryanarayana, C. (2008) *Prog. Org. Coat.* **63** 72–78.

[2] Boura, S.H. (2012) *Prog. Org. Coat.* 75 292–300.

[3] Mirabedini, S.M. (2012) *Colloid Surface A* **394** 74–84.

The effectiveness of the self-healing film formation can be increased by adding a ***corrosion inhibitor***. For steel preferred inhibitors are amines, they are well adsorbed on the surface (usually self-assmebled) closed to form a film on it. The most effective of them are long-chained, which form exceptionally hydrophobic insulator layer. Such as ***octadecylamine*** (***ODA***), which can withstand the corrosive effects of the hot steam and air as well[6,7].

Wide range of polymers are suitable for ***shell formation***. Among them, formaldehyde polycondensate resins have good adhesive ability and can be produced relatively ***cheaply and quickly***. Most of the core-shell capsules in the field of self-healing coatings rest on cross-linked ***urea-resorcinol-formaldehyde*** shell[8].

For the preparation of core-shell capsules, liquid ***core material*** is emulsified in a non-miscible liquid medium, e.g. formed oil-in-water (o/w) or water-in-oil (w/o) emulsion. The shell-forming component is dissolved in the discontinuous phase, in the continuous and discontinuous phase separately, or in the continuous phase, and subsequently these monomers, during shell forming reactions (addition, condensation) establish a solid polymer layer at the polar-apolar medium interfaces, around the emulsified droplets. This preparation method serves for the urea-formaldehyde-resorcinol shell either[9].

The literature of linseed oil-filled urea-formaldehyde shell capsules, to which I applied during my work, has a short history[1]. In the examination of corrosion resistance of the microcapsules-containing coatings there is only a few example in the literature, eg. impedance spectroscopy and a few more salt spray chamber test. Generally the visual assessment is preferred. The results of the few tests show that the linseed oil-filled capsules after injury provide a protective effect to the coating compared to the references.

Anti-fouling coatings

In the last few decades, nanotechnology has opened roads for ***silver as nanoparticle***. It became part of the scientific research of antibacterial and biocide materials. The biocidal effect by the silver nanoparticles

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[4] Nesterova, T. (2012) *Prog. Org. Coat.* **75** 309–318.

[5] Behzadnasab, M. (2014) *Colloid Surface A* **457** 16–26.

[6] Ge, H.H. (2000) *Appl. Surf. Sci.* **156** 39–46.

[7] Rohani-Rad, A. (2003) *Corros. Eng. Sci. Technol.* **38** 79-80.

[8] Kumar, A. (2006) *Prog. Org. Coat.* **55** 244–253.

[9] Nesterova, T. (2011) *Prog. Org. Coat.* **70** 342–352.

(Ag **n**ano**p**article: AgNP) and the migration of ionic silver attach them against certain forms of life, reflected in the catalytic oxidative reactivity of the silver, cellular electron transfer channels unravel, DNA unwinding obstruction, etc.[10].

Silver is examined in coatings; ***thin layers and paint*** as well. To ease the administration of AgNPs in the coating, carriers are often used. During my silver 'packaging' I was looking for primarily organic and biodegradable or biocompatible carriers, keeping in mind the future medical applications. ***Biopolymers*** (***gelatin***, glutathione, keratin, alginate, chitosan, starch, etc.) because of their natural frequency, their low cost, biocompatibility, biodegradability, and their good AgNP circuits, are considered as carriers. It is also important that biopolymers' amino and hydroxyl groups or oxygen atoms stabilize the local Ag^+ ions, and the solution is already assured and the reduced form silver AgNP in the subsequent solid matrix appears with a uniform distribution.

The AgNP containing micro/nano-biopolymers are generally prepared in ***four main steps***, with an order depending on intended use of the product. They include polymer shaping (fibers: spinning, extrusion, microspheres: mainly w/o emulsification system); Crosslinking of the polymer chains (precipitation <alginate>, crosslinker <eg aldehydes.>); silver introduction into the polymer (swelling in Ag^+-containing solution) and silver ion reducing into metallic nanoparticles.

III. Aiming

My aim was to elaborate microcapsules with urea-resorcinol-formaldehyde shell, and a linseed oil core mixed with corrosion inhibitor and drier. The capsules serve as additives in 50-100 microns thick self-healing coatings used on carbon steel plates.

I intended to investigate and explain the effect of some reaction parameters (pH, catalyst, stoichiometry) on the shell thickness and morphology. Besides that with the co-encapsulation of linseed oil and drier or corrosion inhibitor, the efficiency of the self-healing phenomenon might be improved. To precisely follow the healing process, I considered a variety of electrochemical measurements.

My goal was also to benefit the film forming properties of gelatin to develop anti-fouling coating with this polypeptide. Another aim of my work was to elaborate gelatin-based microcapsules containing silver

[10] Li, Q. (2008) *Water Res.* **42** 4591– 4602.

nanoparticles for bio-deposition inhibitor applied in paint no thicker than 100 microns. I chose gelatin because of its low price and the availability.

My expectations of the capsules were as follows: to accommodate the diameter of the coating thickness, with minimum swell in water and the paint solvent, in addition to ship paint the appropriate amount of the long-term release of ionic silver to prevent microorganisms from adhering to the coating.

I attempted to search the appropriate choice of biopolymer (gelatin) cross-linking reagent for the preparation of appropriate shape and size of product. I intended to produce the silver nanoparticles within the biopolymer by *in situ* reduction.

As part of the work for the encapsulation reaction optimizing, the interpretation of the effect of changed parameters, the construction and testing of the product itself and the delivery capacity of the coating, and finally checking the effect of the antifouling coating with gelatin.

IV. Experimental methods

I prepared core-shell structure microcapsules for self-healing coatings by emulsion polymerization, wherein the continuous aqueous phase contained the shell materials (urea, resorcinol, formaldehyde), pH adjusters (HCl, NH_4Cl) and the surfactant poly (vinyl alcohol). Emulsified linseed oil phase and dissolved therein a desiccant (Co-octoate) and corrosion inhibitor (octadecylamine ODA) together formed a liquid capsule core.

I followed the diameter, thickness and the morphology of the shells of microcapsules with optical microscopy, scanning electron microscopy and transmission electron microscopy (SEM, TEM).

I observed the drying of linseed oil (occurring in presence of corrosion inhibitors and driers) with infrared spectroscopy - following the decrease in the intensity of typical absorption bands of C=C bonds of unsaturated oils.

I demonstrated the success of encapsulation of linseed oil with microscopic images, Fourier transform infrared spectroscopy (FTIR) and thermogravimetry.

The capsules were administered in different coatings (epoxy resin, cover paint, combined paint (primer and topcoat in one) (5%) on carbon steel plates which were roughened by sandblasting. The dry, 50-100 microns thick coatings were scratched (20-200 microns wide blades) to observe the elementary steps of self-healing. 'Self-healing' ability of coatings after injury was checked out during corrosion tests, in different solutions (NaCl; NaCl + Na_2SO_4; $HClO_4$ + $NaClO_4$ - solu-

tions). The coatings were evaluated visually and instrumentally: by scanning electrochemical microscopy and electrochemical impedance spectroscopy.

By cross-linking with glutaraldehyde I formed gelatin layer on glass slides for anti-fouling purposes. Into the layer I mixed a quaternary ammonium salt (BARQUAT MD 50) and tested in a cooling water media with mixed microbal population for 5 days.

I produced gelatin-based solid matrix structure microcapsules for antifouling paint as additives. To prepare a product with the appropriate shape and size, I found that the aldehyde cross-linking of gelatinous solution emulsified in an oily phase is a suitable method. I figured out that with the addition of another aldehyde-reactive chemical, urea, the crosslinking density that determines the release capacity of the capsule and its swelling characteristics can be adjusted. The aqueous solution of the components of capsules contained gelatin, urea, formaldehyde and silver nitrate. This was emulsified in a continuous oily phase, linseed oil. I obtained the silver nanoparticles reducing the silver nitrate precursor dissolved in the gelatin solution with formaldehyde, which I used for crosslinking also.

With this complex process I realized in parallel the shaping of the capsule, the setting of its shape and size, embedding and reduction of ionic silver into nanosilver.

The diameter size and shape of the capsules I produced by the above optimized reaction, was observed by SEM. Swelling in aqueous solvent medium was measured using an optical microscope. I used FTIR and TEM, X-ray powder diffraction, to identify the chemical structure of the capsule and the phase of the active substance. I followed the release of silver from capsule with inductively coupled plasma optical emission spectrometry (ICP).

By visual inspection I followed the impact of leachable silver on live microorganisms proliferation (mostly algae) in natural water sample, I measured the Ag-delivery capability of the coatings with capsules, compared to coatings into which I mixed other compounds of silver ($AgNO_3$, Ag_2CO_3). With fluorescence microscopy, in natural water sample I observed the effect of the coating containing nano-encapsulated silver on controlling biofilm formation.

V. Results

Self-healing coatings

Systematically varying parameters of the encapsulation process

(mixing intensity and duration, the concentration of surfactant and stoichiometry, pH and reaction time) with a powerful speed mixer I could develop narrow size distribution emulsions in 5 to 25 microns size range which were stable for several hours. I pointed out that thickness and roughness of the capsule shell can be controlled by changing reaction stoichiometry, pH and duration.

Between the shell thickness and the urea concentration or the reaction time (the other parameters are not changed) from 0 to 600 nm region I found a nearly linear relationship. Like the connection between the outer shell and the surface roughness of the urea concentration. Another factor in determining the skin roughness is the pH, which (the other parameters are not changed) in the range of 3.5 to 4.5 has a more serious effect, causing rough surface. Along higher or lower values the roughness is reduced.

The linseed oil core of the core-shell microcapsule would be an ideal 'healing' agent that solidifies in a short time after it escapes the capsule, and effectively insulate the exposed metal in the wake of the scratch environment. I pointed out that the linseed oil I used needed six days of consolidation. Largest amount of inhibitor soluble at room temperature, 2% was added to the oil, but this elongated the solidification process over one month. I set the ideal drying time at 5 h. The oil with 1 v/v% Co-octoate can dry in 5 h, the composition containing 2% inhibitor needs 2 v/v% Co-octoate to reach this reduced 5 hours[11].

I have demonstrated the successful encapsulation of the linseed oil optically and relying on structural heterogeneity resulting from the different physical and chemical properties of the capsule shell and the filling I quantified it by thermogravimetry and infrared spectroscopy.

With optical methods (optical and fluorescence microscopy) I proved the elementary steps of the process of self-healing in case of coatings with capsules: the effect of capsules splitting upon scratch kind injury; linseed oil escaping during this and film forming[12].

For the first time, I investigated the corrosion processes taking place in the micro dimension vicinity of scratches, in an encapsulated linseed oil containing scratched (epoxy) coating. Scanning electrochemical microscopy map (linear, surface) - and a time scan was performed in close proximity to scratches, corrosion processes of ionic iron dissolution and dissolved oxygen depletion were measured amperometrically.

[11] Szabó, T. (2014) *Prog. Org. Coat.* Közlésre benyújtva
[12] Szabó, T. (2011) *Prog. Org. Coat.* **72** 52–57.

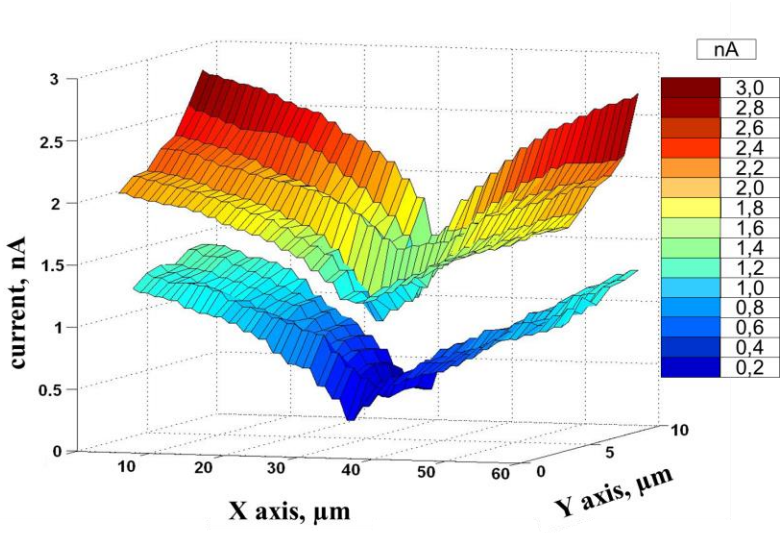

Fig. V.1. Three-dimensional representation of the oxygen reduction current measured at -0.7 V against Ag / AgCl / KCl reference electrode, along the scratches made in the 'y' direction, two hours after immersion. The top and bottom surface shows the epoxy coating with and without microcapsules, respectively.

Fig. V.1. shows the SECM microelectrode panning shots along a 20 microns wide scratch cut in the epoxy coating. The curved surfaces show the current measured by the microelectrode on potential required for the reduction of dissolved oxygen. The measured current is proportional to the dissolved oxygen present in the vicinity of the scratching. It is inversely proportional to the corrosion, thus oxygen that was measured was not "consumed" by corrosion. The top surface belongs to the encapsulated coating, the bottom current scan belongs to the reference sample.

The difference between the two surfaces demonstrates the insulating ability of linseed oil[13].

Unlike the SECM, from electrochemical impedance spectroscopy (EIS) one can get information about the entire sample. The results of the permeability of the coating, the resistive and capacitive impedance, etc. can be inferred.

During EIS measurements I compared the resistance (polarization resistance, R_p) values of scratched coatings with microcapsules of different drier and inhibitor content upon addition of 0,5 M NaCl solution

[13] Pilbáth, A. (2012) *Prog. Org. Coat.* **75** 480–485.

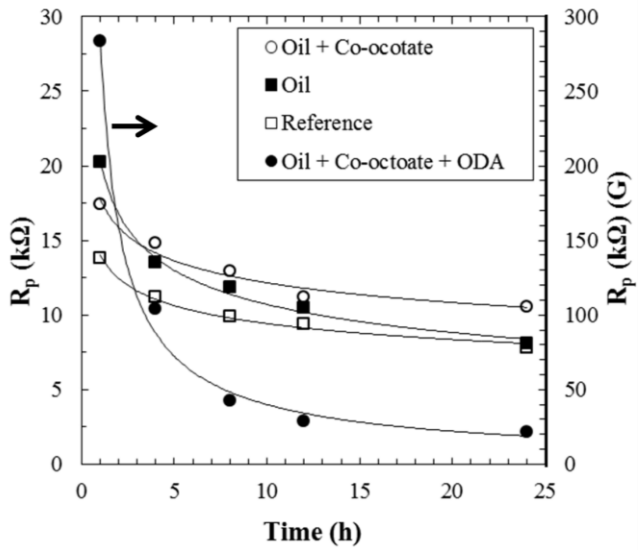

Fig. V.2. Changes in the polarization resistance of the scraped coating layers as a function of time; 1,4,8,12, and 24 hours after the addition of 0.5 M NaCl solution. The examined types of coatings: oil capsule with 1 v/v% Co-oktoate (○); oil capsules alone (■); reference without capsules (□); oil capsule with 2 v/v% Co-octoate and 2% ODA (●). **Last values on the right 'y'- axis are shown.**

Fig. V.2. show temporal changes of the resistance (1, 4, 8, 12 and 24 hours values) derived the Nyquist diagrams.

As expected, resistances of the coating without capsules are minimized. Any more paint with a capsule had higher impedance (derived from the polarization resistance) in comparison with the reference coating. These differences depend on the drying degree of the linseed oil film and the presence of corrosion inhibitor. I found that the increase in resistance in case of the linseed oil without additives is approx. 1.2x, linseed oil with 1% v/v drier is approx. 1.3-fold, the inhibitor-containing linseed oil (2%) with drier (2% v/v) is approx. the average 10-fold, comparing to the reference during the 24 hour corrosion test.

The measurements proved that the linseed oil - if released from the capsule and hardened - increased the protection of the damaged coating. When a chemical inhibitor is present in the capsule, this protection, which is characterized by an increase in the value of Rp, significantly increases[11].

The fluorescence microscope images on Fig. V.3. show cross-linked gelatin coatings with 500 microns thickness.

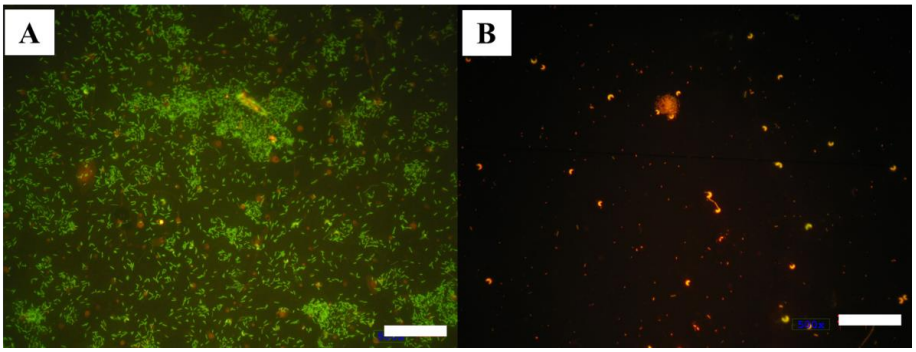

Fig. V.3. Cooling water soaked crosslinked gelatin layer without additive (A) and cross-linked gelatin layer with BARQUAT MD 50 biocide (B). The scales indicate 50 microns.

The coating of crosslinked gelatin with BARQUAT MD 50 successfully ***prevented the bio-fouling***[14] (Fig. V.3.B), while on the reference I experienced intense layer of microorganisms (V.3.A), with the main component of *Desulfovibrio desulfuricans*. Crosslinking (curing agent) did not affect the efficiency.

With a ***new type of emulsion polymerization*** gelatin based, silver containing capsules of 8–15 microns in diameter, produced for anti-fouling coatings, I reduced the swelling of gelatin in water with the co-polymerization with urea. I changed the stoichiometry of the capsule matrix forming components (urea, gelatin) to get a 0.1% ***swelling***, and this value did not increase when examined in organic solvent. The capsules remained stable in both media. I named the obtained optimum swellable sample ***AgNP@GMP***[15] (silver nanoparticle in gelatin microparticle).

During infrared spectroscopy measurements I experienced shift and intensity reduction of typical primary amine and Amide A, -I-II,-III absorption bands of polypeptides. In addition, absorption bands of methylene and methylol groups from the formaldehyde appeared. This showed the ***chemical cross-linking*** of capsule matrix, confirming the presence of minimal swelling.

The overall silver content of the capsules were determined by ICP. Position of the agent within the matrix was visualized in ion beam-

[14] Telegdi, J. (2010) *Mater. Corros.* **61** 1000-1007.
[15] Szabó, T. (2014) *Prog. Org. Coat.* **77** 1226–1232.

thinned microtome-cut capsule slices by transmission electron microscopy (TEM) (Fig. V.4.).

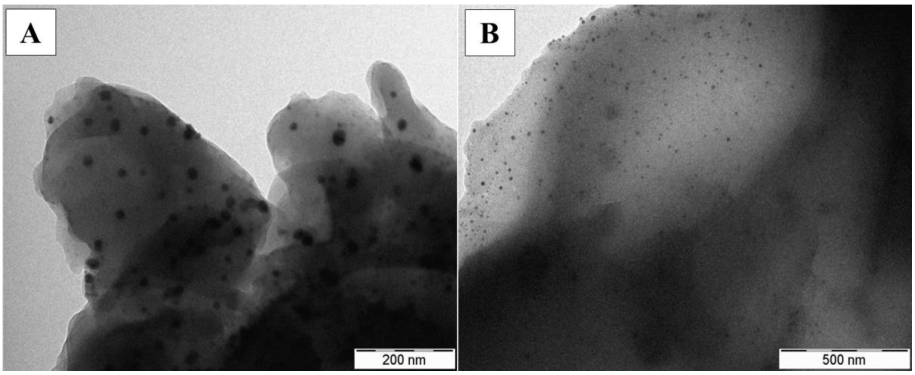

Fig. V.4. TEM micrographs of silver nanoparticles (A) and their distribution in the modified gelatin matrix with lower magnification (B).

Fig. V.4.A shows <20 nm size nanoparticles reduced in situ in the crosslinked gelatine microcapsules. On Fig. V.4.B their homogeneous local distribution in the matrix is observed. X-ray powder diffraction proved that these particles are ***metallic silver nanoparticles***, with the average size of 18 nm.

ICP quantitative release studies showed that the silver ion in aqueous media is released from the capsule. During almost a month, compared to unmodified, but the same silver-containing gelatin 30% silver escapes while from the AgNP@GMP only 3%. Thus, this production method allows one order of magnitude slower, ***sustained release*** of the ionic silver.

Testing the effect of the leachable silver biocide directly from capsule I concluded that very low concentrations of silver emitted in the above experiment ***does not affect the growth of algae***.

I mixed the capsules in boat paint (without default agent) in 5%, and measured the silver-release capability. As a comparison, I used coatings with other silver compounds ($AgNO_3$, Ag_2CO_3). During a two-month investigation, the nitrate and carbonate-containing paint lost 80% and 40% of their total silver content, respectively. While the AgNP@GMP-containing coating had a rate of only 0.7%, which is on average ***two orders of magnitude difference***.

From the paint coatings discussed above, I tested the ***anti-fouling efficiency*** of the silver carbonate and the AgNP@GMP containing ones in ***natural water sample*** for seven month. Result of this experiment are shown on Fig. V.5.

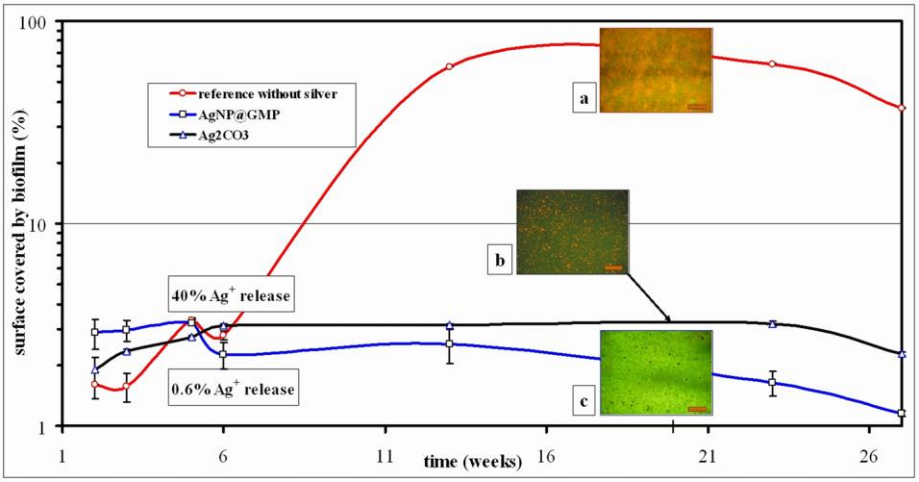

Fig. V.5. The curves illustrate the size of developed biofilm on painted plates (% of sample surface) immersed in lake water for 27 weeks. The curves represent the non-additive (**red**, '**a**'), silver carbonate (**blue**, '**b**') containing and encapsulated nano-silver (**black,** '**c**') containing coatings. The inserted pictures illustrate the 21st weekly coverage.

Shown in the diagram, the curves illustrate the development of biofilm, consisting mainly of algae, (as % of the surface coverage) versus time. On the built-in fluorescent microscopy images, the reddish discoloration indicates the bio-fouling. One can see that the fouling on the reference sample is about 90% formed in a relatively short period of time, within 11 to 12 weeks. On the contrary, the biofilm on the silver carbonate and AgNP@GMP samples is almost negligible, 2-3%, formed over the entire time of the experiment. Logarithmic spacing of the 'y' axis illustrates the magnitude of differences between the coatings

This experiment demonstrated that the paint - containing encapsulated nano-silver (AgNP@GMP) is at least as good bio-repellent such as silver carbonate containing (tested broad spectrum bio-repellent). It is essential, however, that the release studies, previously conducted by, showed that at the 6th week the active ingredient content in the carbonate containing coating is only 60% - in contrast to the capsule coating paint with its 99.4%, almost the entire quantity. So the AgNP@GMP additives can provide two orders of magnitude ***longer-term protection against the bio-fouling***[15].

VI. Thesis

1. By clarifying the urea-resorcinol-formaldehyde and gelatin-urea-formaldehyde polymerization conditions (temperature, stirring speed and the type and proportion of additives, etc.), I realized the synthesis of microparticles with controlled composition and physical properties. [*Szabó*; 2011, 2014]

2. I prepared microcapsules with urea-resorcinol-formaldehyde shell and linseed oil core, capable of oxidative polymerization, and proved that epoxy model coatings and commercial paints with these capsules exhibit self-healing effect. [*Szabó*, 2011]

3. I was the first who ran electrochemical measurements for detection and quantification of anti-corrosion effect after injuries of self-healing coatings containing linseed oil-filled capsules. With scanning electrochemical microscopy, in the micron range, I measured the Fe^{2+} dissolution and O_2 consumption along the scratch that is responsible for the corrosion. I identified significant corrosion inhibition. This is attributed to the protective effect of the linseed oil, which I confirmed for the entire coating with electrochemical impedance spectroscopy. [*Pilbáth*, 2012]

4. To accelerate the capsule-based self-healing film formation and to support the healing process from the chemical side I encapsulated Co-octoate drier and a long chain aliphatic amine corrosion inhibitor (octadecylamine) with the linseed oil, respectively. With electrochemical measurements I demonstrated that the as produced capsules provide more efficient protection for coatings than the ones containing only linseed oil. [*Szabó*, 2014 – folyóirat szerkesztőségébe benyújtva]

5. I prepared gelatin layer with biorepellent properties, cross-linked with glutaraldehyde, conatining a quaternary ammonium type biocide, and successfully applied for the first time - to prevent biofilm formation – in cooling water with mixed microbial population. [*Telegdi*, 2010]

6. For the first time, I applied metallic silver nanoparticles in gelatin-urea-formaldehyde microcapsules as additives for underwater coating, for the control of bio-fouling. To fulfil the criteria of a coating application, I have developed a new 'one-pot' synthesis, in which the

formation of the capsule, the fixing of its shape and size, embedding the silver precursor and its reduction all take place in one vessel. [*Szabó*, 2014]

7. With bio-fouling and release experiments I proved that microcapsules elaborated with the cross-linking of the gelatin in the presence of urea, release the silver slower than the not cross-linked capsules. With this restraining effect the capsules used in ship paint, give an effective, long-term antifouling effect to the coating in natural water sample. [*Szabó*, 2014]

VII. Application possibilities

The microcapsules were elaborated for the purpose of practical use. My research aimed to meet the needs of the target, but does not ignore the fundamental structure-property correlations.

Linseed oil capsules with inhibitors developed for self-healing coatings and solid matrix capsules for anti-fouling purposes are kept under investigation, applied in commercial coatings, exposed to realistic environmental effects.

The everyday usage is in reasonable distance, the next few years the harmonisation of the two research directions is expected: mechanical analysis and functional development of the coatings.

The importance of micro and nanoencapsulation as drug formulation is hard to overestimate. It goes beyond the mere application in coatings practice. For example I kept in mind that the technology of gelatin-based slow-release microcapsules shall be flexible, permitting the development, can easily be optimized even for therapeutic use.

VIII. Publications

Publications related to the PhD thesis

Scientific articles:

Telegdi J, Szabó T, Al-Taher F, Pfeifer É, Kuzmann E, Vértes A
Coatings against corrosion and microbial adhesion: Dedicated to Professor Dr. Wolfgang Sand on the occasion of his 60th birtday
MATERIALS AND CORROSION - WERKSTOFFE UND KORROSION **61**:(12) *pp. 1000–1007.* (2010) [IF: 1,075, I: 4]

Szabó T, Molnár-Nagy L, Bognár J, Nyikos L, Telegdi J
Self-healing microcapsules and slow-release microspheres in paints

***PROGRESS IN ORGANIC COATINGS* 72:**(1–2) *pp. 52–57.* (2011) (Original Research Article, Special Issue FATIPEC 2010 CONGRESS) [IF: 2,268, I: 4]

Pilbáth A, Szabó T, Telegdi J, Nyikos L
SECM study of steel corrosion under scratched microencapsulated epoxy resin
***PROGRESS IN ORGANIC COATINGS* 75:**(4) *pp. 480–585.* (2012) [IF: 2,376, I: 4]

Tamás Szabó, Judith Mihály, István Sajó, Judit Telegdi, Lajos Nyikos
One-pot synthesis of gelatin-based, slow-release polymer microparticles containing silver nanoparticles and their application in anti-fouling paint
***PROGRESS IN ORGANIC COATINGS* 77** *pp. 1226–1232.* (2014) [IF: 2,456; I: -]

Tamás Szabó, Judit Telegdi, Lajos Nyikos
Linseed oil-filled microcapsules containing drier and corrosion inhibitor – their effect on self-healing
PROGRESS IN ORGANIC COATINGS (*Közlésre benyújtva*)
[IF: 2,302; I: -]

Book chapter:

Telegdi J, Szabó T, Románszki L, Pávai M
The use of nano-/microlayers, self-healing and slow-release coatings to prevent corrosion and biofouling
In: Makhlouf A.S.H. (szerk.) Handbook of smart coatings for materials protection. Cambridge: Woodhead Publishing Ltd, 2014. *pp. 135–182.* (Woodhead Publishing Series in Metals and Surface Engineering; 64.) (ISBN:085709680X)

Poster presentations:

Szabó Tamás, Telegdi Judit, Nyikos Lajos
Öngyógyuló bevonatokban alkalmazható mag-héj szerkezetű mikrokapszulák előállítása és jellemzése
Oláh György Doktori Iskola PhD konferenciája, 2011.02.03, Budapest

Tamás Szabó, Nikoletta Molnár-Vörös, László Trif, Judit Telegdi, Lajos Nyikos
New types of functional nanomaterials
EuroNanoForum 2011, 2011.05.30–06.01, Budapest

Aranka Pilbáth, Tamás Szabó, Judit Telegdi, Lajos Nyikos
Scanning Electrochemical Microscopy (SECM) study of steel corrosion under scratched microencapsulated epoxy resin
Nanopaprika-Poster 2011 - 1st Virtual Nanotechnology Poster Conference, 2011.

Szabó Tamás, Pilbáth Aranka, Telegdi Judit, Nyikos Lajos
Self-healing and slow-release coatings with core-shell microcapsules and solid matrix microspheres
AMSALS 2012 – Advanced Macromolecular Systems Across the Length Scales, 2012.06.3–6, Siófok

Pilbáth Aranka, Szabó Tamás, Telegdi Judit, Nyikos Lajos
Investigation of self-healing coatings with scanning electrochemical microscopy
Oláh György Doktori Iskola PhD konferenciája, 2012.05.17, Budapest

Szabó Tamás, Pilbáth Aranka, Telegdi Judit, Nyikos Lajos
Self-healing and slow-release coatings with core-shell microcapsules and solid matrix microspheres
10CCC 10th Conference on Colloid Chemistry, 2012.08.29–31, Budapest

Oral presentations:

Szabó Tamás, Telegdi Judit, Nyikos Lajos
Korrózsiógátló inhibitorok mikrokapszulázása
Kémiai Kutatóközpont által rendezett „12. Doki Suli" konferencia, 2009. április 20, Mátraháza

Szabó Tamás, Telegdi Judit, Nyikos Lajos
Mikrokapszulázás emulziós polimerizációs eljárással
MTA Műszaki Kémiai Tudományos Bizottság Anyagtudományi- és Szilikátkémiai Munkabizottsága által szervezett 'PhD hallgatók anyagtudományi napja IX.', 2009. november 12, Veszprém

Szabó Tamás, Telegdi Judit
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