Corrosion of nonprecious metal alloys in dentistry in the presence of common saliva additives

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Abstract
Corrosion stability of metallic materials used in dentistry is a major concern; identification of materials combining high stability and good performance is needed. The corrosion resistance of representative nonprecious metal alloys frequently used in dentistry in contact with artificial saliva solution with various added substances encountered in foodstuffs and in materials used in dentistry, possibly influencing the corrosion has been studied in vitro with electrochemical impedance measurements. Values of obtained corrosion resistances are interpreted in terms of conceivable effects of the additives on the rate of corrosion; they are also compared with previous results obtained with these alloys and additives using breakthrough electrode potentials obtained from slow scan cyclic voltammetry reported before.

KEYWORDS
corrosion, dentistry, electrochemical impedance measurements, lactic acid, nonprecious metal alloys, phosphoric acid, polyacrylic acid

1 | INTRODUCTION

Numerous metals, mostly alloys and amalgams, are frequently used in the manufacturing of fixed and removable prosthetic dentistry. These materials have numerous advantages when compared with other materials like synthetic polymers or ceramics. They can be manufactured by well-established procedures like casting into very precise and highly developed shapes for application as inlay, onlay, filling, and so forth. They are also frequently used as mechanical support structures for partial and complete dentures. A major drawback of all metallic materials is their susceptibility to corrosion. Corrosion under in vivo conditions, that is, in the mouth, may result in the release of potentially toxic corrosion products; it might also negatively affect the mechanical properties and surface appearance of the various parts permanently as well as temporarily installed in the oral cavity.

Corrosion is closely related to the basic properties of a metal or an alloy, in particular, to its electrode potential (its position in the electrochemical series). A more positive, noble electrode potential (for simplicity, most frequently, the so-called standard potential is considered) suggests a lower susceptibility to electrochemical oxidation as the anodic process in corrosion proceeding in the mouth with the electrochemical reduction of omnipresent dioxygen as the cathodic reaction. This has resulted in the use of noble metals, in particular, of gold and of alloys with high cold content, in dentistry. For specific applications (crowns, inlays), financial expenses related to the use of gold and its alloys has grown to an extent not acceptable to healthcare systems in various countries, already in the 80s. This has resulted in the development...
of less expensive materials, for example, palladium-based alloys. Initial concerns regarding their corrosion stability and possible effects of casting procedures have been addressed.

For some applications (dentures), noble metals and their alloys are less suitable because of insufficient mechanical properties. The nonprecious (sometimes also non-noble) metal alloys frequently used for these purposes are composed of a wide variety of metals; consequently, the number of available alloys is large (in Germany in 1994 about 930). According to their composition, they are less noble than gold and its alloys, and thus, are more prone to corrode when in contact with saliva and air. This detail has attracted some attention earlier. Although nickel is frequently considered as being problematic because of its capability to cause allergic reactions, its use in such alloys has not been of noticeable concern after some changes of alloy composition resulted in significant improvements in their corrosion stability. The relatively high corrosion stability of these alloys is certainly due to the passivation and formation of stable surface layers (for an example of such layers formed on chromium-containing alloys, see Ho et al.).

1.1 Methods of corrosion studies

Numerous methods are available to measure the rate of corrosion of metals. Because corrosion of metallic materials in the mouth is mostly an electrochemical process, methods from this field have been considered, in particular, for experimental assessment of corrosion susceptibilities of these materials. Certainly, measurement of the sample under in vivo conditions would be preferable, but except for electrode potential measurements in the mouth, no other method has been found to be applicable and useful. As discussed before, measurements of the electrode potential of a sample spontaneously established in the mouth (open-circuit potential \( E_{oc} \)), which is equivalent to the corrosion potential \( E_{corr} \), are poorly reproducible even under highly controlled in vitro conditions; because of widely varying experimental conditions, this will be even worse under in vivo conditions. It has also been noticed that such data can be interpreted properly only when taking into account the state of a material’s surface and further experimental details hardly reproducible under in vivo conditions.

Because corrosion of metallic materials in vivo is also dominantly an electrochemical process, electrochemical methods have attracted attention in particular for comparative studies aiming at the identification of relationships between alloy composition and corrosion susceptibility and finally of more stable alloys. Cyclic voltammetry (CV) has been considered the most useful experimental method. The influence of the scan rate has been critically examined. Slow scan rate CV has been found to yield results compatible with those obtained with other methods; for considerations of long-term polarization curves, see Hack and Scully. The composition of the electrolyte solution has been found to be of particular importance. In the study reported here, a synthetic saliva solution initially suggested by Meyer was used; a very similar solution was described earlier by Swartz et al. After modifications by Fusayama et al., this synthetic saliva is commonly called “Fusayama saliva.” Its properties are close to those of natural saliva. More recently, a critical re-examination of about 60 saliva solutions has been reported; conclusions do not affect the selection followed here. The selection of Fusayama saliva was also logical to ensure compatibility with previous studies. The influence of biological constituents in the corrosive environment should be considered; a study of a small number of selected alloys in a lab bioreactor has been reported. A critical comparison of characteristic data obtained under such “biological conditions” with the in vitro conditions established, for example, in a Fusayama saliva, is still missing. Such comparison would support the application of corrosion susceptibilities found with synthetic saliva under in vitro conditions and without applying “biological conditions” to real in vivo conditions.

1.2 Previous results of electrochemical corrosion studies with metallic materials in dentistry

Reports on the corrosion stability of palladium-based alloys, amalgams, and nonprecious metal alloys using slow scan CV yielding breakthrough electrode potentials \( E_B \) taken as an indicator of corrosion susceptibility with a higher, that is, more positive value indicating higher stability have been provided. The selected scan rate based on considerations reported earlier (see above) of \( \frac{dE}{dt} = 1 \text{ mV s}^{-1} \) was taken as a compromise between very low, quasi-stationary, scan rates (see also Hack and Scully), resulting in very time-consuming experiments and in excessive electrochemical transformations in case of electrode potential excursions into the potential range of active metal dissolution as well as gas evolution at sufficiently negative potentials. Both may possibly result in changes of active surface area, the formation of reaction products, and changes in the electrochemical environment close to the examined surface, although this approach is closest to the
electrochemical equilibrium at any potential. With too high scan rates \( (dE/dt > 10 \text{ mV} \cdot \text{s}^{-1}) \) electrochemical processes may be overlooked; for a critical discussion, see Weber et al.\[27\]

In the case of amalgams,\[34,35\] slow CV has failed because no characteristic breakthrough potentials could be detected; instead, typical corrosion currents were evaluated. Another inherent disadvantage of CV as the method applied so far is the significant deviation of the applied electrode potential(s) from the open circuit or rest potential \( E_{oc} \), which is equivalent to the corrosion potential \( E_{corr} \) in these studies\[17\] including electrode potential excursions into regions where metal dissolution may become significant. Therefore, electrochemical impedance measurements at the spontaneously established corrosion potential have been applied to previously studied materials, including palladium-based alloys\[36\] and amalgams\[37\]. Ratings of corrosion susceptibility could be established similar to those based on slow scan CV.

Elsewhere, possible effects of saliva ingredients supplied by common foodstuffs (phosphoric acid [PA]),\[38\] by cariogenic bacteria forming lactic acid (LA) or by materials used in dentistry (also PA) present locally during the handling of phosphate cements used to fix crowns and bridges; and of polyacrylic acid (PaA) being a constituent of resin cements (e.g., Relyx\(^*\) Unicem self-adhesive universal resin cement, 3M ESPE) have been examined.\[12,15\] These additives may play a role in local phenomena like color changes of the gingiva; they may also influence corrosion by passivating the alloy surface or accelerating corrosion by either forming protective surface layers or accelerating the anodic electrode reaction. Taking advantage of impedance measurements (measurement at electrochemical equilibrium, i.e., at \( E_{oc} = E_{corr} \)) significantly shorter measurement time even when taking into account the data evaluation selected alloys have been re-examined; results are reported and discussed in the following.

2 | EXPERIMENTAL

Selected alloys currently available in Germany, representing the two major classes cobalt- and nickel-based alloys and frequently applied taking into account the results of earlier studies\[12,15\] have been examined. In addition, two different casting procedures were utilized. Their actual composition as measured using electron probe X-ray microanalysis (EPXMA; CAMBAC SX 100) is reported in Table 1 (see also Refs.\[14,15\]). The alloys were cast into samples of various shapes (a disk for EPXMA [diameter, 30 mm; thickness, 2 mm] and cylinders for CV [length, 40 mm; diameter, 5 mm]) using two different casting procedures (for details on casting procedures and commercial instrumentation see Refs.\[2,6,7,11–15\]).

The cylinders were polished before electrochemical measurements with abrasive paper (wet paper, type 240, 320, 400, and 600), cleaned in an ultrasonic bath with ultrapure water, and rinsed with acetone and ultrapure 18 M\(\Omega\) water (Seralpur Pro 90C). Subsequently, they were connected to a sample holder fitted with a tapered joint. A conventional electrochemical H-cell with a corresponding tapered joint and cell compartments for a platinum sheet counter electrode and a saturated calomel electrode acting as a reference electrode separated from

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**TABLE 1** Composition of studied alloys as provided by the manufacturer and as measured (see also Refs.\[14,15\])

| Nickel-based alloys | Ni | Cr | Mo | Si | W | Ce |
|--------------------|----|----|----|----|---|----|
| Winon 99           | 65 | 22.5 | 9.5 | 1 | -- | -- |
| Measured           | 64.6 | 21.6 | 9.5 | 1.25 | -- | -- |
| Ni/Cr/Mo/Si        | 66 | 13 | 7 | 0.8 | 7.5 | 5 |
| Measured           | 65.5 | 12.9 | 7.2 | 0.7 | 7.6 | 5.2 |

| Cobalt-based alloys | Co | Cr | Mo | Si | W | Ce |
|---------------------|----|----|----|----|---|----|
| Remanium 2000       | 61 | 25 | 7 | 1.5 | 5 | -- |
| Measured            | 61.8 | 22.8 | 8.2 | 1.1 | 4.5 | 0.1 |
| Co/Cr/Mo/Si/Fc/Mn   | 33 | 30 | 5 | 1 | 29 | 1.5 |
| Measured            | 33 | 30.5 | 5.2 | 1.1 | 29.6 | 0.4 |

**Note:** The values are represented as mass percent (%).

Color assignment—**CCO**: centrifugal casting with a protective gas blanket after melting in an open flame.

**VCRG:** Vacuum pressure die casting with protective gas after melting in a resistance heated furnace under inert gas.
the main compartment by glass frits was used; for further
details, see Refs. [6,7]

Synthetic saliva, as suggested by Fusayama et al.,[32]
containing 0.4-g KCl (Acros Organics), 0.4-g NaCl (VEB
Laborchemie Apolda), 0.69-g NaH₂PO₄·H₂O, 0.005-g
Na₂SO₄·H₂O (Grüssig GmbH), 0.795-g CaCl₂·H₂O (Grüssig
GmbH), and 1-g urea (Fluka) per cubic decimeter dis-
solved in 18 MΩ water was used as electrolyte solution; its
pH was 4.7–5.00. This electrolyte solution has been iden-
tified as being closest to natural saliva in terms of com-
parability of the results of the corrosion study.[29] All
chemicals, as well as the added acids, were of analytical
purity; they were used as received. The cell was immersed
in a water bath kept at 37°C. The solution was saturated
with pressurized air filtered with activated carbon instead
of nitrogen or argon to keep the composition of the elec-
trolyte solution as similar as possible to the in vivo si-
tuation. This way a dioxygen concentration resembling the
one encountered in the mouth was established. Dioxygen
is needed for the cathodic reaction in the corrosion pro-
cess; a deaerated solution can hardly be taken as resem-
bling natural conditions in the mouth and measurements
obtained with such solution may not be representative of
actual corrosion conditions.

Electrochemical impedance measurements were per-
formed at \( E_{oc} \) after a stable electrode potential value had
been established (after a few minutes) on a potentiostat
IviumStat Electrochemical Interface in the frequency range
5 kHz to 1 Hz, with seven data points per frequency decade
at a sine wave amplitude of 5 mV. Measurements of im-
pedance and \( E_{oc} \) were repeated five times per sample. For
data handling, in particular, for fitting of the obtained
impedance data, Boukamp software (version 2.4) was used.
A Randles-type equivalent circuit (Figure 1) was assumed
as has been employed in previous studies reported by the
present authors[36,37] with a constant phase element \( Q \)
instead of a simple double-layer capacitance, taking into
account the nonideal purely capacitive behavior[39–43]; for
a broader discussion see Fu et al.[44] All parameters of all
equivalent circuit elements have been fitted; only the va-
lues of \( R_{ct} \) (i.e., the corrosion resistance \( R_{corr} \)) relevant for
this comparative study are listed and discussed below.
Averages of five measurements are reported, no further
statistical treatment was applied.

3 | RESULTS AND DISCUSSION

Results of the EPXMA surface elemental analysis of the
alloys yielded the results displayed in Table 1. They
have been discussed in detail in a previous report, in
particular, with possible relationships between surface
enrichment/segregation and other crystallographic
effects possibly influencing corrosion behavior.[14,15]

Conclusions reported there will be introduced below as
far as relevant.

A typical set of results showing changes of impedance
values in their graphical representations upon addition of
the various studied additives is shown in Figure 2.

Values of \( E_{oc} \) (vs. SCE) and results of electrochemical
impedance measurements obtained by nonlinear least-
square fitting are shown in Table 2; only the relevant
values of \( R_{corr} \) are displayed. Because values will be
compared only within this report, no transformation
with respect to surface area (neither geometric nor true
electrochemically active surface area[45]) is needed. The
quality of a fit was judged both by inspecting total error

![Figure 1](wileyonlinelibrary.com)  
**FIGURE 1** Equivalent circuit used in impedance measurements

![Figure 2](wileyonlinelibrary.com)  
**FIGURE 2** Results of impedance measurements (top: Nyquist plot, bottom: Bode plot); symbols: measured data points, lines: results of fit and simulation [Color figure can be viewed at wileyonlinelibrary.com]
values and visual agreement between measured and fitted data. Typical examples are displayed in Figure 2.

Conversion of \( R_{\text{corr}} \) into a corrosion current \( I_{\text{corr}} \) or corrosion current density \( j_{\text{corr}} \) according to

\[
j_{\text{corr}} = \frac{R \times T}{n \times F \times A \times R_{\text{ct}}}
\]

(with all symbols having the usual meaning) would be possible only if the corrosion reaction equation would be known, in particular, the value \( n \) of the number of electrons transferred in the anodic corrosion reaction. Given the rather variable composition of the alloys and the conceivable numerous different metal oxidation reactions, such conversion would be rather unreliable, actually not scientifically well supported. But this transformation is not needed: A comparison of \( R_{\text{corr}} \) is just sufficient to judge corrosion susceptibility. In Table 2, an alloy with a lower value of \( R_{\text{corr}} \) would be more susceptible to corrosion than an alloy with a relatively higher value. The influence of the casting procedure on the corrosion susceptibility for palladium-based alloy has been examined extensively before, no influence was found. In previous studies of nonprecious metal alloys reported by the present authors, no influence of casting procedure on values of \( E_{\text{B}} \) was found. Given the possible effects of alloy composition on \( R_{\text{corr}} \) in the present study, any such conclusions would be highly speculative. The values of \( E_{\text{oc}} \) closely trend with the values of \( R_{\text{corr}} \), that is, a higher value of the latter, implying lower corrosion susceptibility is accompanied, with a more positive value of \( E_{\text{oc}} \).

According to the listed results, Wirobond LFC is the most stable, N/P2 is the least stable. This comes as a slight surprise because the former alloy contains a very substantial fraction of the fairly non-noble iron. By comparison with the breakthrough electrode potentials \( E_{\text{B}} \) reported earlier, this finding is not unexpected. For comparison, the respective values from these reports are listed in Table 3.

Table 3 shows that exactly the same sequence was observed before; even the two further alloys Wiron 99 and Remanium 2000, showed rather similar values of \( E_{\text{B}} \). The strikingly positive value of \( E_{\text{B}} \) found for Wirobond LFC may be due to the formation of a protective passivation

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**Table 2** Values of \( R_{\text{corr}} \) (in \( \Omega \)) and \( E_{\text{oc}} \) (in V) obtained with different saliva solutions

| Solution additive | None       | PA        | LA        | PaA       |
|-------------------|------------|-----------|-----------|-----------|
| **Nickel-based alloys** |            |           |           |           |
| Wiron 99          | 3.92 \times 10^4 | -0.145    | 2.69 \times 10^4 | -0.100    |
| N/P2              | 2.48 \times 10^4 | -0.238    | 1.88 \times 10^4 | -0.098    |
| **Cobalt-based alloys** |            |           |           |           |
| Remanium 2000     | 5.44 \times 10^4 | -0.246    | 4.91 \times 10^4 | -0.074    |
| Wirobond LFC      | 1.64 \times 10^4 | -0.151    | 2.45 \times 10^4 | -0.216    |

Note: Color assignment—CCO: centrifugal casting with a protective gas blanket after melting in an open flame. VCRG: Vacuum pressure die casting with protective gas after melting in a resistance heated furnace under inert gas.

**Table 3** Values of \( E_{\text{B}} \) (in V) versus saturated calomel electrode as obtained with different saliva solutions (data in Refs. [14,15])

| Solution additive | None     | PA       | LA       | PaA       |
|-------------------|----------|----------|----------|-----------|
| **Nickel-based alloys** |          |          |          |           |
| Wiron 99          | 0.72     | 0.91     | 0.8      | 0.55      |
| N/P2              | 0.55     | 0.83     | 0.82     | 0.44      |
| **Cobalt-based alloys** |          |          |          |           |
| Remanium 2000     | 0.73     | 0.93     | 0.8      | 0.6       |
| Wirobond LFC      | 0.92     | 0.9      | 0.86     | 0.88      |

Note: Color assignment—CCO: centrifugal casting with a protective gas blanket after melting in an open flame. VCRG: Vacuum pressure die casting with protective gas after melting in a resistance heated furnace under inert gas.

Abbreviations: LA, lactic acid; PA, phosphoric acid; PaA, polyacrylic acid.
layer, in particular, with phosphate ions present in the saliva solution. Iron phosphate coatings are well-established in corrosion protection.

The addition of PA resulted in significant decreases of $R_{\text{corr}}$, in the case of Wirobond LFC by almost an order of magnitude. Values of $E_B$ were increased upon addition of PA significantly, only in the case of Wirobond LFC, $E_B$ barely changed. These changes of $E_B$ were attributed to the passivating effect of PA acting by the formation of poorly soluble phosphates. The formation of such layers will be enhanced by positive electrode potential excursions, which result in the anodic formation of metal ions, which, in turn, will subsequently form said passivating precipitates. During impedance measurements such potential excursions are absent; this might explain the observed apparent discrepancy. Verification of this suggestion may be possible by repeating impedance measurements after intentional poten-

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The effects of the addition of PaA are different for the studied alloys. $R_{\text{corr}}$ does change only slightly for the alloys, while only for Wirobond LFC, it decreases by an order of magnitude. The significant acceleration of corrosion thus implied may be related to the major iron fraction.

4 | CONCLUSIONS

Electrochemical impedance measurements can be used to measure corrosion resistance values of nonprecious metal alloys in dentistry with different compositions and prepared by different casting procedures. Nickel-based alloys did not show significant effects of additives on the corrosion resistance, while that of cobalt-based alloys were more visible.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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REFERENCES

[1] K. Dermann, H. Rentsch, J. Rothaut, Nachr. Chem., Tech. Lab. 1995, 43, 535.
[2] C. Mülders, Ph.D. Dissertation, Universität Bonn 1989.
[3] K. J. Bundy, Crit. Rev. Biomed. Eng. 1994, 22, 139.
[4] P. Schmutz, N. C. Quach-Vu, I. Gerber, Electrochem. Soc. Interface 2008, 17, 35.
[5] H. Kaesche, Die Korrosion der Metalle, 3rd ed., Springer-Verlag, Berlin 1990.
[6] C. Mülders, M. Darwish, R. Holze, J. Oral Rehabil. 1996, 23, 825.
[7] M. Darwish, C. Mülders, R. Holze, Dtsch. Zahnarztl. Z. 1996, 51, 101.
[8] R. Herber, B. Tiemann, R. Kees, C. L. Davidson, H. Weber, H. Gründler, F. Sperner, H.-W. Gundlach, P. Dorsch, H. Schwickerath, K. Eichner, G. Forck, R. Kees, Wissenschaftliche Reihe: Medizinische und technologische Aspekte dentaler Alternativlegierungen, Vol. 1 (Ed: Forschungsinstitut für die zahnärztliche Versorgung), Forschungsinstitut für die zahnärztliche Versorgung, Köln 1983.
[9] E. Lenz, Zahnärztl. Mitteilungen 1993, 83, 37.
[10] E. Lenz, Swiss Dent 1991, 12, 7.
[11] D. Kunzmann, H. Döring, E. Rahm, R. Holze, CLB Chem. Labor Biotech. 2005, 56, 58.
[12] A. Klostermann, D. Kunzmann, H. Döring, E. Rahm, R. Holze, Korrosionsstabilität edelmetallfreier Nickel- und Kobalt-Basis-Dentallegierungen unter Einwirkung von Speichelkomponenten, in Elektrochemische Grundlagenforschung und deren Anwendung in der Elektroanalytik, Proceedings of ELACH 7, Waldheim, Germany, 2006, (Eds: U. Guth, W. Vonau) KSI, Waldheim 2006, pp. 53–56.
[13] D. Kunzmann, E. Rahm, R. Holze, M. Darwish, Die Korrosionsstabilität edelmetallfreier Dentallegierungen, in GDCh-Monographie 23 (Eds: J. Russow, H. J. Schäfer) GDCh, Frankfurt 2001, pp. 377–378.
[14] E. Rahm, D. Kunzmann, H. Döring, R. Holze, Microchim. Acta 2006, 156, 141.
[15] A. Klostermann, E. Rahm, R. Holze, ECS Trans. 2010, 25, 203.
[16] W. F. Ho, S. C. Wu, C. W. Lin, S. K. Hsu, H. C. Hsu, J. Appl. Electrochem. 2011, 41, 337.
[17] X. Xie, R. Holze, ChemTexts 2018, 4, 5.
[18] J. Wirz, S. Steinemann, Phillip J. Restaur. Zahnmed. 1987, 4, 81.
[19] B. Westerhoff, Diploma Thesis, Universität Oldenburg 1991.

[20] K. Liefeith, G. Hildebrand, D. Kraft, E. Lenz, E. Mann, Swiss Dent 1994, 15, 7.

[21] G. Hildebrand, D. Kraft, K. Liefeith, E. Mann, E. Lenz, Mater. Corros. 1995, 46, 157.

[22] J. Geis-Gerstörfer, H. Weber, Dtsch. Zahnarztl. Z. 1987, 42, 91.

[23] N. K. Sarkar, E. H. Greener, J. Oral Rehabil. 1977, 4, 55.

[24] E. Stender, H. Marx, Dtsch. Zahnarztl. Z. 1984, 39, 775.

[25] E. P. Lautenschlager, P. Kollmannsperger, K. Eichner, Dtsch. Zahnarztl. Z. 1985, 40, 1107.

[26] H. Engel, Ph. D. Dissertation, Universität Mainz 1983.

[27] H. Weber, K. H. Sauer, W. Paulissen, Dtsch. Zahnarztl. Z. 1985, 40, 838.

[28] H. P. Hack, J. R. Scully, Galvanic Corros. 1986, 42, 79.

[29] J. M. Meyer, J. N. Nally, J. Dent. Res. 1975, 54, 678.

[30] J. M. Meyer, Corros. Sci. 1977, 17, 971.

[31] M. L. Swartz, R. W. Phillips, D. El Tannir, J. Dent. Res. 1958, 37, 837.

[32] T. Fusayama, T. Katayori, S. Nomoto, J. Dent. Res. 1963, 42, 1183.

[33] U. Lenz, B. Melle, K. Liefeith, G. Hildebrand, D. Kraft, Swiss Mater. 1996, 8, 6.

[34] B. Westerhoff, M. Darwish, R. Holze, J. Appl. Electrochem. 1992, 22, 1142.

[35] B. Westerhoff, M. Darwish, R. Holze, J. Oral Rehabil. 1995, 22, 121.

[36] D. Liu, X. Xie, R. Holze, Int. J. Electrochem. Sci. 2019, 14, 4074.

[37] D. Liu, X. Xie, J. Roscher, R. Holze, Mater. Corros. 2020, 71, 949.

[38] H. Langendorf, K. Lang, Z. Lebensm.-Unters. Forsch. 1961, 115, 400.

[39] H. Göhr, Ber. Bunsenges. Phys. Chem. 1981, 85, 274.

[40] J. Shi, W. Sun, Corr. Sci. Prot. Technol. 2011, 23, 387.

[41] H. Katayama, J. Japan. Inst. Met. 2014, 78, 419.

[42] S. D. Talian, M. Bester-Rogac, R. Dominko, Electrochim. Acta 2017, 252, 147.

[43] S. M. R. Niya, M. Hoorfa, Electrochim. Acta 2016, 188, 98.

[44] L. Fu, Q. Qu, R. Holze, Y. Wu, J. Solid State Electrochem. 2019, 23, 717.

[45] X. Xie, R. Holze, J. Electroanal. Chem.

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