# Dezincification of brass in drinking water of higher hardness and lower chloride concentration

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Abstract

Brass is nowadays one of commonly used materials in contact with drinking water because of low price and its good machinability. In the past, lead was added to brass to improve machinability in concentrations of six or more weight percentage. Unfortunately, brasses that contain more than 15% of zinc are prone to dezincification which causes leaching of lead to water. Therefore, in the last decades the use of lead alloyed brasses was reduced due to the health risk. It was shown by various studies that dezincification is a selective corrosion attack of zinc rich phase of brass which is affected by chemical and physical drinking water properties. While the influence of chemical properties is well studied, physical are not. Despite many literature data revealing that only waters of particular pH level, moderate hardness and higher chloride concentrations cause dezincification of brass, real- cases worldwide showed a different behaviour in certain occasions.
The main aim of our study is to present results of investigation of a case study where increased concentrations of lead had been detected in drinking water. Detailed inspection revealed that the reason was in the dezincification of brass component although it had been used in the water not recognized as aggressive to cause this type of corrosion process.

**Key words:** brass, dezincification, leaching, drinking water

## 1. Introduction

Brasses are indispensable materials for products used in drinking water installation systems. Valves, connecting fittings, water meters, and other elements, are made by different processing (mechanical, casting, forging) and in order to improve above all mechanical finishing, lead (Pb) is added. Concentration of Pb depends on the quality and varies up to several percent by weight.

With the tightening of the maximum permissible amounts of Pb in water by World Health Organization (WHO) and subsequently Drinking Water Directive (DWD) due to the health risks, the concentration of Pb was reduced in 2013 down to maximum 10 mg Pb/L. In European Union (EU) suitability of materials for contact with drinking water has to be defined by each state. However, the EU most developed regulations for metals in the contact with drinking water (4 MS Acceptance schemes), maximum allowable concentration of Pb in brass and in galvanic coating is set. On the other hand, in the United States of America (USA), this is defined in a Public Law (PUBLIC LAW 111–380—JAN. 4, 2011): the maximum allowed concentration of Pb in material depends upon the total surface of material alloyed with lead in respect to the whole surface of installation in the contact with drinking water.

The drinking water chemistry varies significantly among different areas and has a significant influence to the leaching of brass. The water properties and its impact to increased concentrations of Pb in the water due to the leaching were well studied in the past [1-8].

One of the most reverberating and cited study in this field is the study of Turner [4] from 1961 where he compared visual observation of meringue corrosion products on brass with two water parameters; chloride concentration and bicarbonate concentration in water, the latter served as a measure of alkalinity. This researcher constructed so-called Turner diagram that shows influence of chloride and bicarbonate content in the water to the brass dezincification which lead to formation of meringue deposits on the brass surface. Recent studies conducted by Edwards's group in USA have shown that Turner diagram cannot be applicable to all qualities of drinking water, but only to those in a limited pH range where meringue dezincification can occur [3, 5].

The present study shows the case study where corrosion of brass occurred in water with lower concentration of chloride and high alkalinity. Such water in Turners case did not cause dezincification. However, the behaviour observed in the present study was just the opposite.

## 2. Description and analytical observation of the study

In the present study brass materials which suffered dezincification after a few years of exposure in internal drinking water system in multi apartment building, as well as the chemical parameters of corresponding drinking water, were investigated.

Soon after the detection of the excessive lead concentration in the drinking water (> 10 μg Pb/L), all components of pipeline system possibly containing lead were systematically examined (visually and by metallographic analysis of cross sections of brass). These materials were: galvanized pipes, brass valves and brass water meters. It was found out that the dezincification occurred on all investigated water meters in the building, additionally; all internal surfaces of galvanized pipes were severely corroded. However, the only possible source of lead was suspected to be brass water meters. There was one such water meter per apartment.

Brass water meters were made from various types of brasses containing different concentrations of main elements such are Cu, Zn, Pb, Sn, Ni, Fe and others. A detail composition of two representative selected water meter bodies is presented in the Table 1.

Table 1: Chemical composition of two water meter bodies. All results are in weight percentages.

| ZAG | %Zn | %Pb | %Sn | %Fe | %Ni | %Si | %Al | %Cu | %As |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 34.1 | 1.5 | 0.13 | 0.21 | 0.111 | 0.0183 | 0.71 | 62.9 | 0.024 |
| **B** | 31.62 | 2.36 | 0.82 | 0.664 | 0.519 | 0.0513 | 0.735 | 62.9 | 0.0126 |
| CW617N*/CuZn40Pb2 | / | 1.6-2.2 | <0.3 | <0.3 | <0.1 | <0.03 | <0.05 | / | / |
| CC770S*/ CuZn36Pb-C | / | 0.2-1.6 | <0.3 | <0.3 | <0.2 | / | 0.5-0.7 | / | 0.04-0.14 |

* Brass qualities approved by 4MS [9]

Since only concentrations of Pb, Cu, Zn and Fe were systematically monitored at the taps (presented at the Table 2) where increased lead concentration was observed, there are unfortunately no available data about other water parameters which had influence to the dezincification of brass.

Table 2: Concentrations of lead, zinc and iron in water, measured in installation lines where brass materials A and B were installed

| | Zinc [μg/L] | Lead [μg/L] | Iron [μg/L] |
|---|---|---|---|
| **A** | 2500 | 17 | 310 |
| **B** | 540 | 92 | 1700 |

Regular analyses of water composition at the source are available, while the information about bicarbonate alkalinity is available only for groundwater that feed the source. (Table 3).

Table 3: Physical and chemical composition of water at the source and underground water, which supply source

| Parameter | pH* | Conductivity $mS/cm^2$* | Amonium mg/l* | Nitrite mg/l* | Nitrate mg/l* | Sulphate mg/l* | Chloride mg/l* |
|---|---|---|---|---|---|---|---|
| Analysed value | 7.4-7.6 | 540-800 | <0.013 | <0.07 | 6-29 | 12-29 | 23-34 |

| Parameter | TOC mg/l | Hydrogencarbonate $gHCO_3/L$** | Carbonate hardness NT** | m-alkality m-eqv/L** | Bicarbonate alkalinity as $CaCO_3$ mg/L - 1,22 x hydrogencarbonate** |
|---|---|---|---|---|---|
| Analysed value | <0.5 | 468.9 | 12.1 | 4.3 | 321.8 |

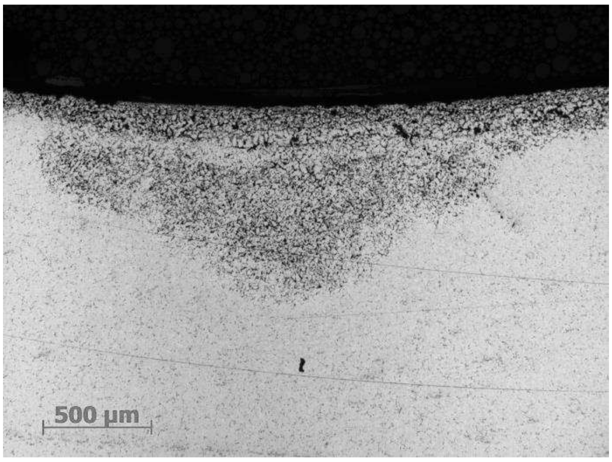
* result of water analysis at the source

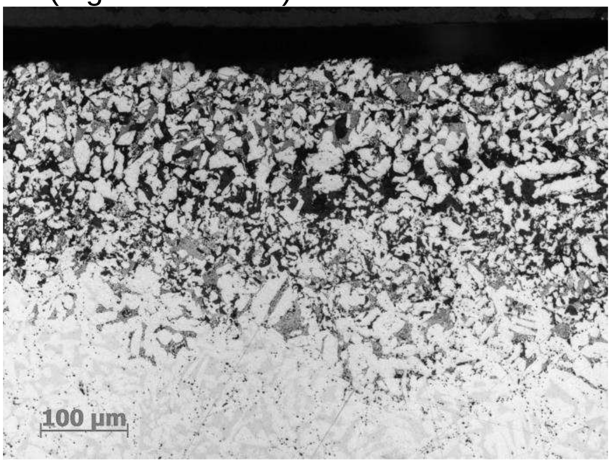
** result of groundwater analysis

### 3. Results and discussion

For the detailed additional analysis, metallographic investigation of the materials A and B (see chemical composition of investigated materials in the Table 1) for water meter bodies were considered. Chemical composition of the material A is almost within the range of allowed elemental concentrations required for material in the contact with drinking water, regulated by 4MS. Only the As concentration is too low. In this type of alloy, arsenic is added to prevent dezincification of alpha brasses (containing less than 35 % of Zn). On the other hand, material B contains too high concentration of Fe; also concentration of Pb is higher than in the case of material A.

After removal from the internal installation, interior of both corroded water meters was of very similar appearance – covered with light green layer of zinc oxide. Metallographic analysis performed on cross section of both materials has shown severe dezincification in the case of material A (Figures 1 and 2).

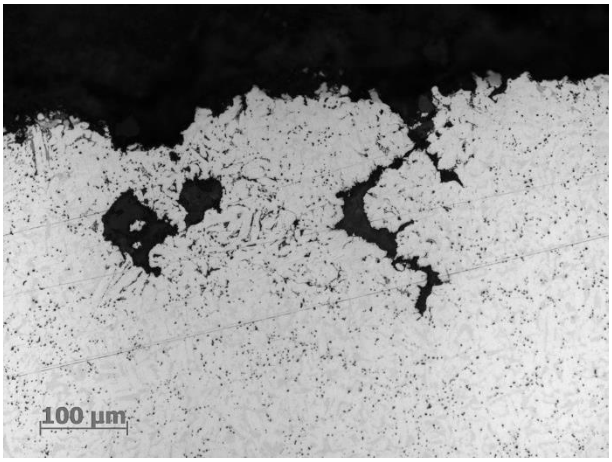


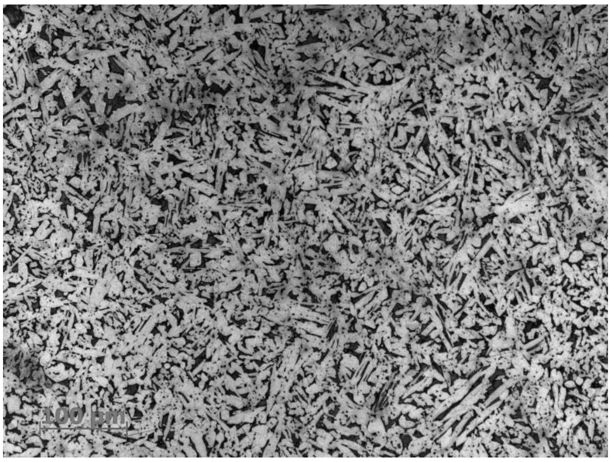



Figures 1 and 2: Severe dezincification of material A, etched by Klemm II

Microstructure of brass of element A consists mainly from α-phase, which is expected regarding to Zn/Cu ratio from chemical composition. β-phase is observed only in minority. In this type of alloy, small concentrations of arsenic are added in order to prevent dezincification. Unfortunately, the concentration of this element in this alloy was probably too low, therefore severe dezincification occurred. Dezincification was observed across all surfaces being in contact with the drinking water, the depth of dezincification front measured up to 1 mm.

Examination of cross section of brass water meter B has revealed porosity sites under the surface and presence of dezincification spots.





Figures 3 and 4: Dezincification of material C – beside dezincification also porosity is observed (left); microstructure with α and β phase (etched with Klemm II)

Based on chemical and metallographic composition (duplex brass with α and β phase) it can be assumed that the material B should be more prone to dezincification. However, this assumption was not proved with metallographic analysis (no significant dezincificated locations were observed), although higher concentrations of lead were detected in water in the internal installation of material B. Indeed, measured Pb concentrations depend a lot upon the sampling of water (flow regime before sampling) which was not known.
Great amount of studies that show the influence of water chemistry to dezincification of brass was done in the past [3]. One of the most cited was done by Turner [9] where the influence of the chloride concentration and temporal hardness to the dezincification of duplex brass in various waters sampled all over UK in 1960s was presented graphically (Figure 5).

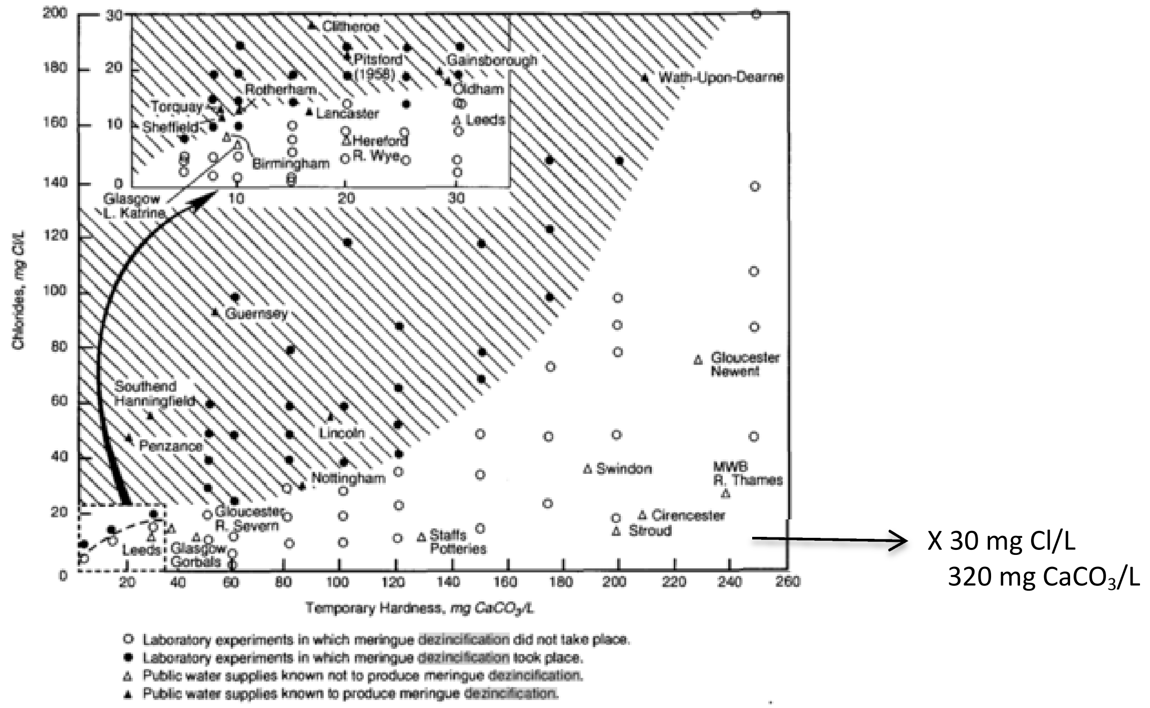



Figure 5: Influence of water composition on meringue dezincification (source: BNF Technology Centre, Oxon, England) [4]

As it can be seen from the Table 3, measured concentrations of chlorides in water into which investigated materials were exposed, were not very high, that is approximately 30 mg Cl/L. On the other hand, concentration of $CaCO_3$, also called alkalinity or temporal hardness, was very high – around 320 mg $CaCO_3$/L. In the Turner diagram, such combination of chloride and bicarbonates (as temporal hardness) was from the practical studies recognised as non-dangerous for dezincification of brass, which is in contradiction with our observations in the studied case.

There are several reasons why the water with lower concentration of chlorides and high temporal hardness in that case caused leaching of zinc, and consequently migration of lead from brass:

- pH of this water was lower than pH of waters tested for the construction of Turner diagram (pH of waters studied for Turner diagram construction was always above 8.3),
- Turner's diagram was constructed based on examples were meringue type of brass corrosion was observed visually (meringue deposits were formed on the surface) and
- only duplex brasses containing $\alpha$ and $\beta$ phase were taken into consideration in the case of Turner diagram.

In the present case too high concentrations of lead migrated to the water from the water meters of brass. In the case of material A, the material was $\alpha$ brass, with too low addition of As to prevent dezincification. The dezincification front observed at the surface was very deep and homogenous – around 500 $\mu$m thick.

In the case of material C not many spots of dezincificated microstructure of duplex brass were revealed with metallographic examination. However, concentration of lead in examined water was very high, approximately 10 times too high regarding to DWD currently allowed concentration which is 10 $\mu$g Pb/L. From the results of surface examination it can be seen that the surface is not even, but rough – based on this observation it might be assumed that the surface is corroded. One of hypothesis is, that $\beta$ phase was leached out because of the dezincification, and subsequently the material on the surface become porous and brittle and locally cut off into water. That can be observed as uniform corrosion at the surface.

## 5. Conclusion

In the present study, where brass materials were exposed in drinking water in one location is Slovenia, it was observed, that they corroded irrespectively to the low chloride level and high bicarbonates in the water.

Water composition was considered "safe zone" water composition according to the Turner diagram, and the following conclusions have been drawn to explain opposite behaviour:

- Material A was $\alpha$ brass which was not studied by Turner for the construction of the diagram, shows sensitivity to dezincification,
- The pH of local water into which materials presented in this paper were exposed was 7.4, on the other hand, the pH of waters investigated for the construction of Turners' diagram were above 8.3 and
- Surface of material B, which is duplex brass, corroded uniformly - only small spots of dezincification were observed, however the surface was very rough.

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