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Material parameters affecting degradation processes of Al-brasses in pipe systems

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ABSTRACT

Purpose: As construction material of cooling pipe systems there are often used Al-brasses because their high thermal conductivity, mechanical workability and corrosion resistance. In the pipes liquid media of various chemical compositions are flowing by different rates. It means that the material is loaded mechanically also chemically what results in synergy effect on degradation. Susceptibility to corrosion-erosion damage of four Al-brasses manufactured by different producers is investigated because in operation conditions they have different reliability and lifetime.

Design/methodology/approach: By studying of their microstructure, surface state, selected mechanical properties and corrosion characteristics the parameters which affected chemical-mechanical degradation were evaluated. Experimental methods are SEM, EDX and spectral analyses, measurement of microhardness and roughness.

Findings: By actual obtained results it was identified that in spite of very similar chemical composition differences in mechanical and corrosion behaviour are affected by technology of manufacturing. It can explain their different durability in operating conditions.

Research limitations/implications: To identify more precisely the main parameters important for degradation resistance in various flow media the original experimental device is designed and constructed. The device makes possible to test Al-brasses in various flowing media by the same mail at three flowing rates. By long time lasted experiments in the one it is able to simulated operation specification. Results of the device are not presented yet because they are just in progress.

Practical implications: Obtained results will be very helpful for choice of Al-brasses for required operation conditions according important properties which were experimentally verified.

Originality/value: It means contribution to economy by material saving in operation by available choice and design and construction of original experimental device.

Keywords: Al-brass; Corrosion; Microstructure; Surface; Roughness; Microhardness; Corrosion-erosion

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MATERIALS

1. Introduction

The research of mechanical-chemical degradation susceptibility of four Al-brasses (DIN 17660 (CuZn20Al2As) is evoked by practice experience. The Al-brasses working in comparable conditions (service temperature is usually in the range from 40 to 80°C, the liquid medium is flowing about 0.5-2 $m.s^{-1}$) differ quite markedly in durability. Al-brasses in fluvial or supply water are practically resistant to corrosion. Typical corrosion products with protective properties are created on surface. The material reduction is about 8-18μm per year. Corrosion rate grows with increasing temperature, oxygen or chlorides content and by flowing is influenced too. The mass loss in mentioned environments can reach values 15-35 μm per year. Corrosion damage of the Al-brasses is not homogenous, but corrosion pits are usually created. The Al-brasses are material often used in industry for cooling pipe systems with flowing liquid media where high corrosion resistance and reliability is expected. The goal of our research is studying of substantial parameters as chemical composition, microstructure and surface properties affecting corrosion behaviour of the selected Al-brasses. The followed parameters with an influence on degradation processes are very important in operation conditions of pipe systems because they determine the life-time and safety of cooling systems [1-8].

2. Experiments and results

2.1. Characterization of experimental materials

In the Table 1 chemical composition of the tested brasses performed by spectral analysis is presented. All the tested Al-brasses (M1, M2, M3, M4) have lower content of Cu and higher content of Zn in comparison to the standard (DIN 17660). The other elements are in a proper amount (in the specimen M3 was identified little more of Fe and in the specimen M4 is slightly exceeded value of Ni. The mentioned differences in chemical composition are not marked for corrosion and mechanical behaviour of the brasses. Elements influenced dezincification of this type of brass as manganese and iron are not in essential amounts [9,10]. The microstructure of the investigated Al-brasses (shown in Fig.1) is formed by solid solution of alloying elements (α). The grain size (Table 2) and homogeneity of the tested specimens differ. According to authors [11,12] plastic deformation of Al brasses by cold rolling increases general corrosion and dezincification in comparison to fully annealed ones. Conditions of annealing influence microstructure and character of surface oxidation products [13].

2.2. Surface properties

Because the internal surface of pipes is mostly exposed to flowing lquid environment, their resistance to degradation will depend on mechnical and corrosion surface properties. By SEM the internal surfaces were studied and the results are in Figure 2. In the surfaces are observed pores, cracks, pits and on the specimens M2 and M4 some unidentified artefacts. On the surface of the specimen M3 straight furrows along the pipe are visible. Chemical composition (Table 3) shows too differences especially in oxygen content. It means that various oxidation products are created during manufacturing [14].

Roughness of surface has an influence on mechanism and kinetic of the corrosion process because change its real size and can create undesirable crevices [15]. The surface undulation also has an effect on flow condition too [16]. To compare surface geometry the roughness measurements were carried out. Three measurements are made on all specimens in a longitudinal direction and mean values of the profile representative parameters (Ra-arithmetical mean deviation, Rq - root mean square deviation, Rz - maximum height, Rku - kurtosis, Rs - skewness, Rsm - mean width of profile elements) are in Table 4. The diagrams in longitudinal direction for the measured surfaces are shown in Figure 4. Measurements were made according to the standard EN ISO-4287 (Terms - definition – parameters - structure of surface). Character of profiles of the tested specimens is in Fig. 3. The most broken relief of internal surfaces was observed of the specimen M4.

The influence of microstructure and surface state was followed by measurement of microhardness because it is an important parameter of pipe system exposed to flowing medium. The hardness was tested on the internal surface by equipment Zwick/Roller Indentec ZHμ by the Vickers method. In the 20 mm length of specimen 15 measurements of hardness were performed. The mean values of microhardness and standard deviations are demonstrated in Table 5.

Table 1.
Chemical composition of the experimental Al-brasses

	Content of elements [wt.%]								
Sp.	Zn	Al	As	Sn	Mn	Pb	Fe	Ni	Cu
M1	22.49	2.11	0.018	0.004	0.001	0.01	0.02	0.001	75.21
M2	23.43	2.06	0.020	0.022	0.005	0.016	0.05	0.049	74.08
M3	22.65	2.10	0.018	0.002	0.001	0.005	0.08	0.001	75.07
M4	22.07	2.06	0.025	0.014	0.008	0.01	0.02	0.135	75.47

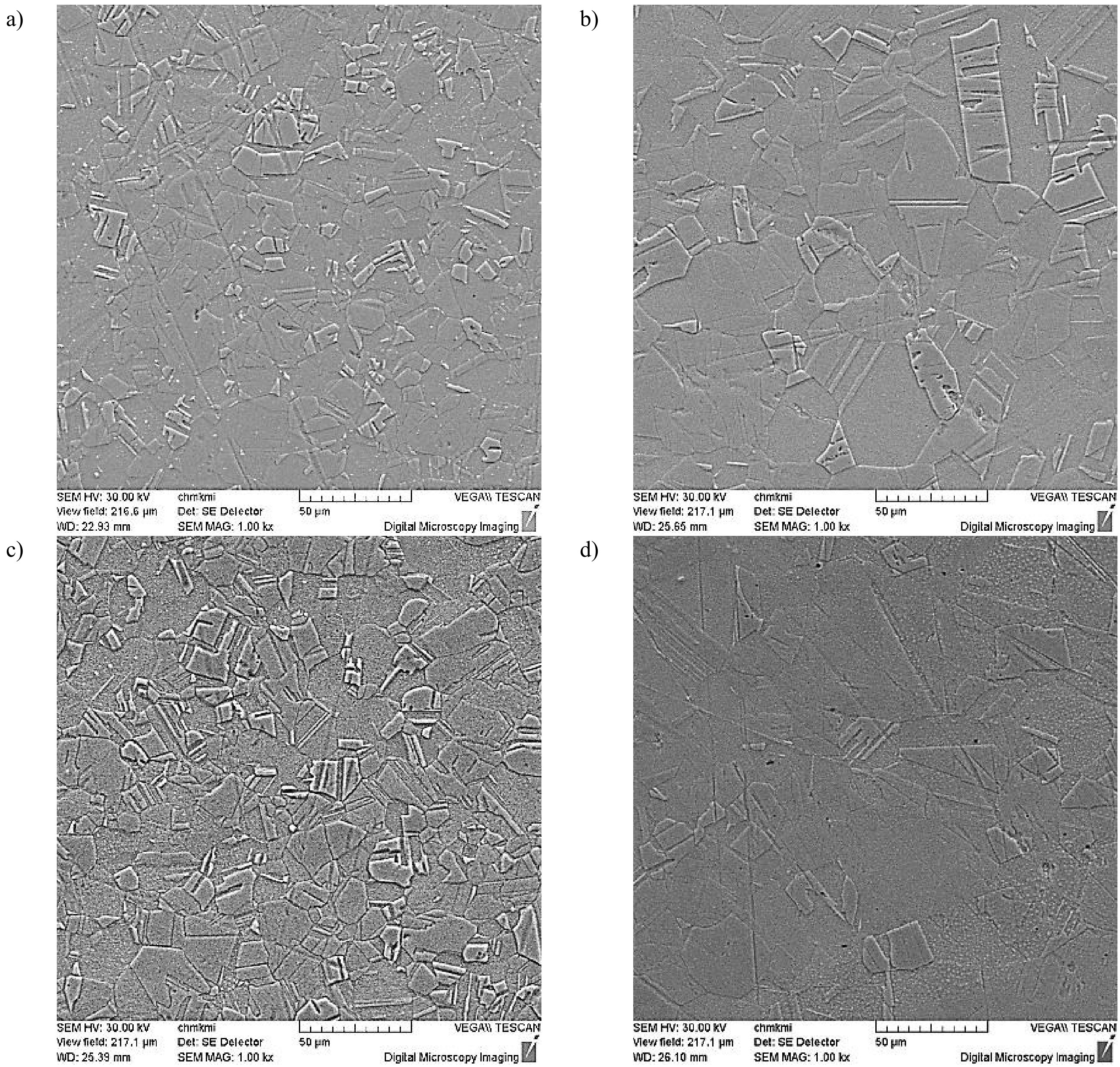


Fig. 1. Microstructure of the Al-brasses by SEM, a) M1, b) M2, c) M3, d) M4

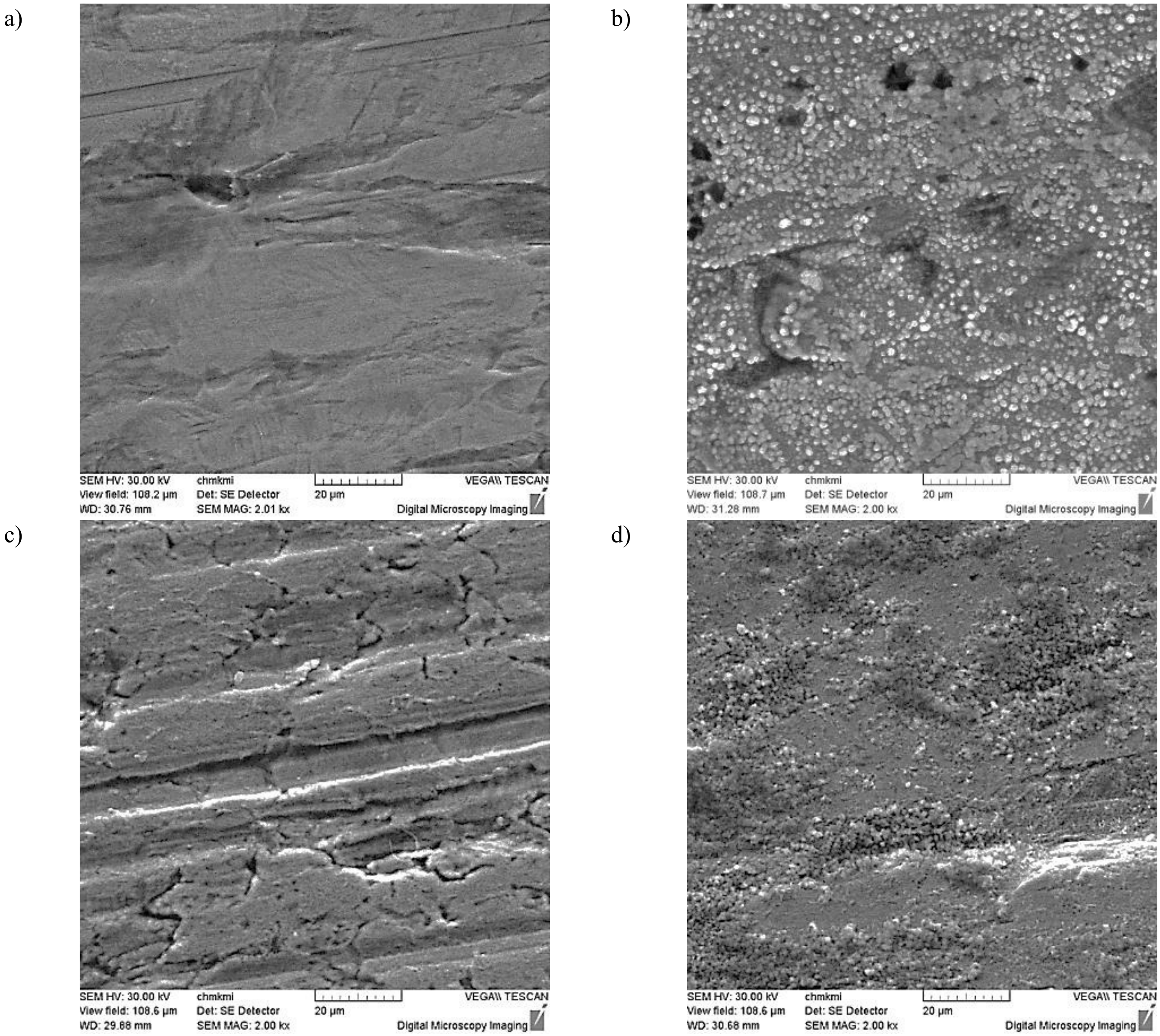


Fig. 2. Microstructure of the Al-brasses surfaces by SEM a) M1, b) M2, c) M3, d) M4

Table 2.
Average grain size of the Al-brasses

Average grain size			
M1	M2	M3	M4
26 µm	42 µm	24 µm	38 µm

The microhardness of the specimen M1, M2, M3 is considered similar but lower value was determined for the specimen M4. This property is dependent on method of production and heat treatment of Al-brasses. With increasing temperature of heat treatment hardness droops that it has to be made very accurately. This fact can affect degradation processes of brasses by flowing liquid in pipe system [17].

Table 3.
Chemical composition of the investigated surfaces

Specimen	wt. %			
	O	Al	Cu	Zn
M1	11.46	3.39	67.67	17.48
M2	14.95	4.38	60.51	19.65
M3	13.47	3.12	65.27	18.13
M4	10.07	4.69	68.04	17.13

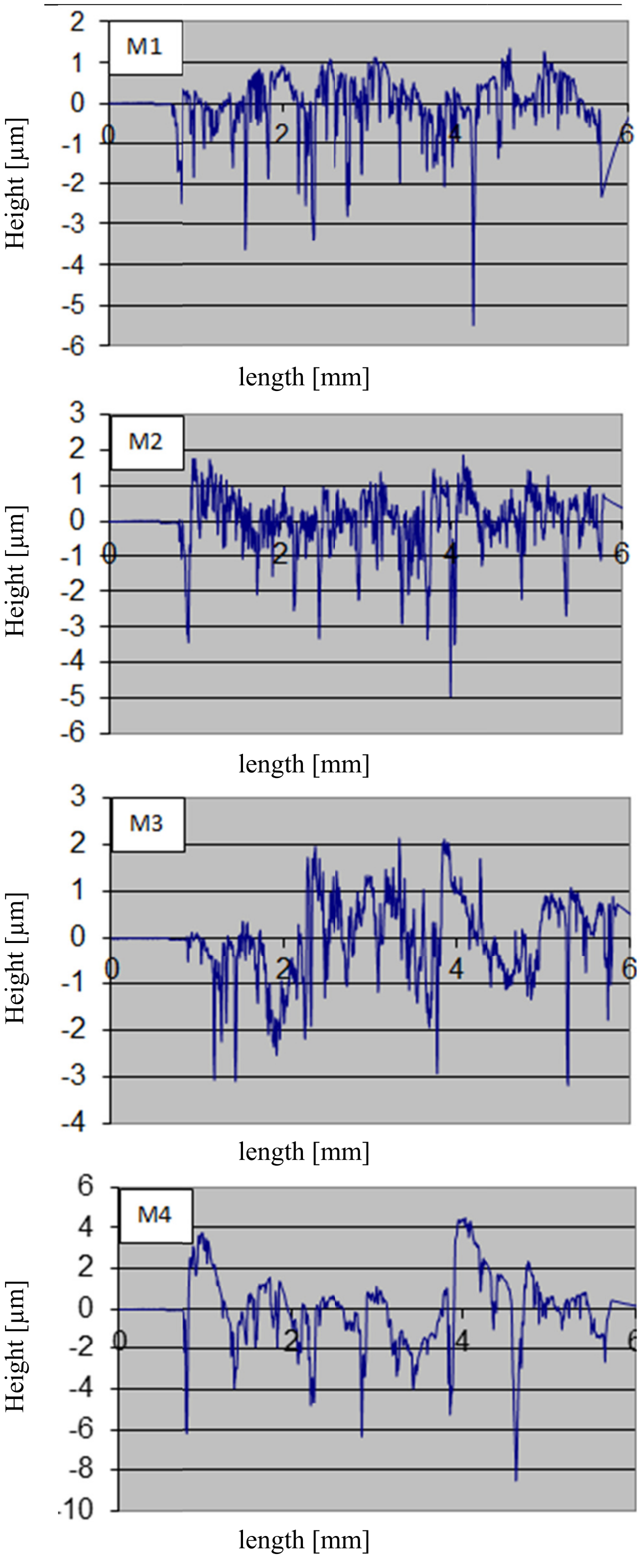


Fig. 3. Characteristic roughness of the tested Al-brasses surfaces

Table 4.
Roughness characteristics of the tested Al-brasses

Specimen	Ra	Rq	Rz	Rku	Rsk	Rsm
M1	0.59	0.830	6.023	7.500	-1.67	0.034
M2	0.571	0.802	6.090	6.567	-1.453	0.025
M3	0.767	0.973	5.537	3.4	-0.62	0.055
M4	1.29	1.747	11.500	4.400	-0.653	0.073

Table 5.
Microhardness of the Al-brass specimens

Microhardness	M1	M2	M3	M4
average	97.53	100.93	98.53	87.93
stand. dev.	3.12	2.79	5.67	6.13

2.3. Corrosion characteristics

Corrosion behavior was identified by potentiodynamic tests. The measured parameters inform about electrochemical stability and rate of metal dissolution in fluvial water. The electrochemical test were performed in three electrode system (CuZn20Al2As) aluminium brass as working electrode with the area 1 cm^2, SCE as reference electrode and Pt counter electrode) using a computer controlled potentiostate/galvanostate VSP. Setting delay was 10 minutes, the potential range of measurement from -200 mV to +400 mV vs. Eoc and the scan rate was 1 mV/s. Temperature was 23°C ± 2°C and the experimental medium was cooling finished water supplied from power-plant. Six measurements were made of every specimen and representative results of potentiodynamic curves are in Table 6 and in Figure 4.

It can be seen that corrosion potentials of specimens M1 and M2 are almost the same and corrosion rates are comparable. The specimens M3 and M4 are less electrochemically stable and kinetic of corrosion is higher. It is supported by microscopically observed amount of corrosion products created during the potentiodynamic testing [18,19]. The specimen M4 with the lowest values of corrosion potential and the highest corrosion rate has all surface covered by continual layer of corrosion products. Corrosion products of the specimens M1, M2, M3 are sporadically excluded on surfaces. Authors [15] indicated effect of microstructure of the Al-brass obtained by annealing at different temperature and time on corrosion properties studying by electrochemical tests. They found that higher temperature of annealing increase corrosion potential and decelerate corrosion rate.

With regards to obtained results the differences of Al-brasses pipes mechanical and corrosion properties were demonstrated. To appreciate their influence in operation conditions (synchronize mechanical and chemical loading in flow media) the experimental device was suggested and constructed. The measurement in it will make possible to follow degradation process of four tested Al-brasses in the same time, the same conditions (composition of solution, temperature etc.) at three different flow rate. The experiment carried out in the device will be long lasting to most approach to real practice conditions [20-23].

Table 6.
Potentiodynamic characteristics of the tested Al-brasses

Specimen	E_{corr} [mV]	i_{corr} [µA/cm^2]	b_c [mV]	b_a [mV]	v_{corr} [mm/year]
M1	-193.999	0.125	86.9	44.3	0.0029
M2	-193.573	0.221	96.4	42.3	0.0051
M3	-240.838	0.360	118.1	44.6	0.0084
M4	-234.430	1.448	147.6	47.0	0.0336

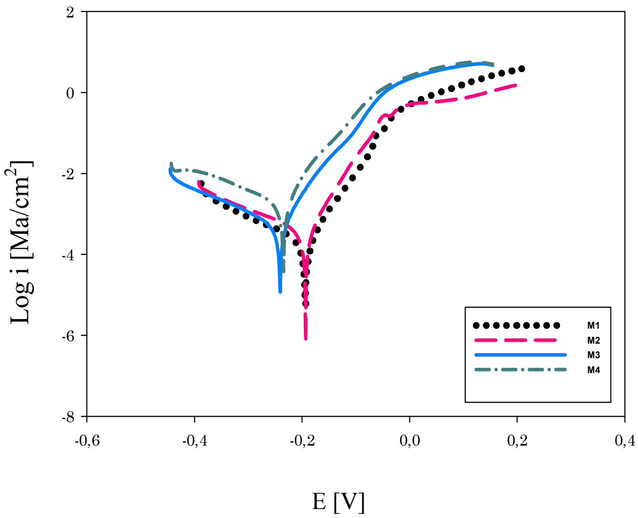
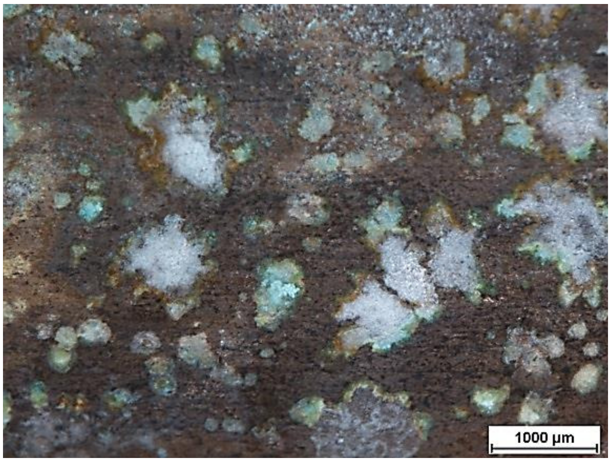
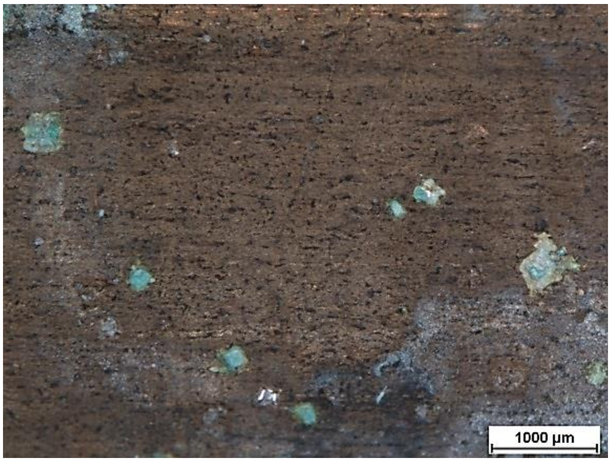
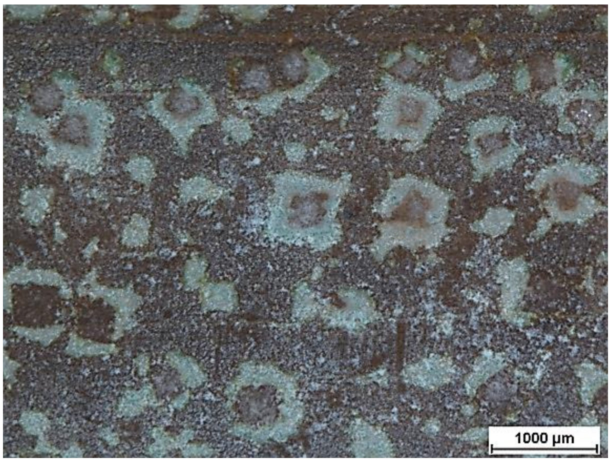


Fig. 4. Potentiodynamic curves of the tested Al-brasses in finished water

a)


b)


c)


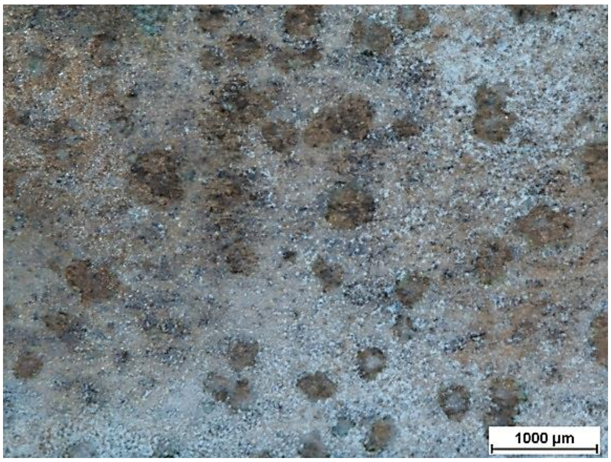
d)


Fig. 5. Character of corrosion products of the tested specimens after electrochemical test, a) M1, b) M2, c) M3, d) M4

3. Conclusions

Based on experimental results obtained by the performed corrosion and mechanical test it can be established:

- The Al-brasses from various producers have very similar chemical composition and it is not premise their substantial influence on corrosion and mechanical behavior.
- Microstructures of the investigated Al-brasses are formed of α solid solution with annealing twins. They vary in grain size and homogeneity and twins amount what is caused by various production methods. These factors have influence on mechanical properties and corrosion behavior. According to our results the brasses with more homogenous microstructure and lower grain size have higher microhardness but explicit effect on corrosion properties was not demonstrated.
- The internal surfaces of the Al-brasses have different topography, roughness and chemical composition too. These parameters affect corrosion behavior (it is supported by results of electrochemical tests).
- By the carried out experiments it is not possible to define contribution of microstructure and surface state expressly. The experimental work will continue by study of degradation processes in flowing corrosion media. Good resistant to corrosion was determined to specimens M1 and M2 and the highest values of hardness for specimen M3. The experiments in flow medium can show which parameter is more effective.
- The specimen M4 is evaluated like the worst from corrosion and mechanical point of view.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME’2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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