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Evaluation of microstructure and chosen properties of zinc and its alloys

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ABSTRACT

Purpose: This paper presents especially the results of microstructure and properties investigation results of selected zinc (Zn) and zinc alloys (ZnAl15). In the frame work of this paper were performed investigations of the microstructure using light and scanning electron microscopy as well as analysis of the chemical composition of the tested materials, there are also carried out.

Design/methodology/approach: The investigations were performed on samples of pure Zn as well as of zinc-aluminium alloy ZnAl115 with the chemical composition conforming with the commercial standard. Material for the investigation was provided in the form of a wire having a diameter of 3 mm and a length of 80 mm, 130 mm and 180mm respectively, subjected to cold working consisting in pulling.

Findings: The presented tests results carried out using light microscopy allowed the determination of the microstructures obtained after the production process of materials from pure zinc and selected zinc alloys. The observations made using the scanning electron microscope revealed that the decohesion after the static tensile strength test the investigated materials are characterized by a regular (circular) fracture. Pure zinc is characterized by the predominance of mixed fracture with the dominance of brittle fracture areas, whereas the zinc alloys reveals rather a ductile fracture.

Practical implications: This paper deal with the investigations concerning structure an properties of pure zinc and zinc alloys with additional elements as well as impurities coming from possible recycling procedure or environmental pollution source and its appliance for further application.

Originality/value: Zinc is the fourth most widely used metal in the world after iron, aluminium and copper.

Keywords: Zinc alloys; Microstructure; Microhardness; Recycling

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PROPERTIES

1. Introduction

Zinc has been applied in many industrial branches, such as building industry, for constructions made of steel, in the process of galvanizing, the automotive industry, metallurgical industry and many others. Its most important role is covering the elements in order to reduce the susceptibility for corrosion. Zinc has become a component of many alloys, in particular: brass, bronze (used among other things for the production of coins) or tombac. It is a component of products such as batteries, rubber, white pain, and many others. Its application continues to grow due to the continuous development of new technologies for production and processing. An important advantage of the production of zinc beyond the corrosion protective function, is the possibility for its recycling from the scrap metal, which is very important in the present shortage of metallic materials, while a stable demand for zinc and its alloys. There are some assumptions, that its share in the future practice will even grow, especially in the evolution of the replacement of some materials with zinc. It is a heavy metal with a density of $7.133 g/cm^3$, crystallising in the A3 crystal lattice revealing anisotropy. Zinc is an element of the II group in the periodic table, beginning the additional zinc-metals family. It is characterized by resistance to atmospheric corrosion (without pollution) that fore its most important purpose is the coating to protect diverse components against corrosion (zinc sheets, tubes, wires). About 30% of zinc available in the world is recovered from zinc recycled: brass, cast steel, galvanized steel, discarded automobiles, household appliances and electrical equipment. Nowadays, this is a huge advantage, because natural resources are steadily decreasing [1-11].

2. Investigations method

The investigations were performed on samples of tree pure Zn castings as a reference value, as well as of four zinc-aluminium ZnAl115 alloy with the chemical composition conforming with the commercial standard, presented in Table 1 and 2. The added elements were iron, copper, magnesium and cadmium in amount up to ca. 0.03 wt. % as presented in table 2.

The Material for the investigation was provided in the form of a wire having a diameter of 3mm and a length of 80mm, 130mm and 180mm respectively, subjected to cold working consisting in pulling. The ZnAl cast signed as 609007[1)] was additionally heat treated, composed of homogenising in a chamber furnace during 6h at a temperature of 250°C.

Observation of the microstructures of the tested materials were performed using light microscopy F-My supplied by Olympus at magnifications in the range of 50-1000 times, as well as a scanning electron microscope Zeiss Supra 35 at an accelerating voltage of 20kV. Analysis of the chemical composition was performed using a ARL3460 spectrometer. Microhardness measurements were performed by Vickers hardness tester according to the standard [13] on the device Galileo Isoscan. The measurements were performed with a load of 1.961N with 10 indentations for one measurement result.

Table 1.
Zinc and its alloys – classification according the material group and chemical composition [12]

Alloy type	Amount of the alloying additives, mass %		Acceptable additives, mass %	
Zn99.99	Zn	min 99.99	total	≤ 0.001
			Pb	≤ 0.005
			Cd	≤ 0.005
			Pb+Cd	≤ 0.006
			Sn	≤ 0.001
			Fe	≤ 0.003
			Cu	≤ 0.002
			balance	≤ 0.12
ZnAl15	Zn	84-86	total	≤ 0.17
			Pb	≤ 0.005
			Cd	≤ 0.005
			Pb+Cd	≤ 0.006
			Sn	≤ 0.001
			Fe	≤ 0.05
			Cu	≤ 0.01
			balance	≤ 0.12

3. Investigation results

By mind of the carried out analysis based on the light microscope structure investigations, it was found, that the microstructure of Zn is characterized by relative large irregular grains (Fig. 1), with the size in the range up to 50µm while the ZnAl15 alloys have a microstructure consisting of smaller grains (Fig. 2). The most dangerous-in terms of properties deteriorations-contaminants present in the zinc are Pb and Sn, because they form a triple low-melting-temperature eutectic (Zn+Pb+Sn), which precipitates at the grain boundaries (Fig. 1). While the ZnAl15alloys are composed of two compounds: the η solid solution, and eutectic (η+α). The η solid solution is a terminal solid solution of aluminium in zinc. The α eutectic is distributed in areas of the η solid solution. In the dendrites there are present at the room temperature some minor secondary separation of the ε phase and alternating α phase which have precipitated as a result of changes in the solid state (Fig. 2). The α phase is converted during the eutectoid transformation and therefore they observed as not uniform precipitations and are coloured dark during etching. Small additions of Mg to the ZnAl15 alloys cause a delay of the eutectoid decomposition of the α phase, but these additions does not stop this decomposition. Whereas the addition of Cu accelerates the eutectoid decomposition. Tables 2-8 show the chemical composition of the tested alloys. ZnAl15 zinc alloys containing up to 15% of Al in the group of middle range Al-containing alloys (8 to 18% of Al). Figures 1-6 show the microstructure of the investigated materials: zinc and its ZnAl15 alloys.

Based on the observations of fracture in a scanning electron microscope it was determined the fracture type of the samples after the static tensile test at room temperature and the effect of the alloying elements on the fracture type. It was found that after the decohesion in a tensile test, all Zn samples and ZnAl15 alloy samples are characterised with a regular (circular) cross-section (Figs. 7 and 8a). Zn samples are characterized by a mixed fracture with a predominance of brittle fracture share (Figs. 7 and 8b). At the fracture of the Zn samples were observed craters and fracture planes with sharp surfaces of the brittle fracture type with visible edges. The ZnAl15 zinc alloy, Fig. 9b) is characterised by a ductile fracture.

Microhardness test results made it possible to determine the effect of alloying elements on the tested zinc and zinc alloys. The highest microhardness (HV) was measured for the zinc casting 033, which has the highest addition of Mg, Cu and Fe, and the lowest value was determined for zinc casting 037. Together with the increase of the cadmium content the microhardness of the Zn alloys decreases. The higher content of the Cd addition and lower copper content reduce the microhardness of the Zn alloys 108. The values of microhardness are showed in Tables 3 and 4.

Table 2.
Chemical composition of the analysed pure zinc and zinc-aluminium alloy

Chemical composition of the investigated alloys, wt. %										
Casting sign 033										
Cast 1	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	99.995	0.0007	0.0014	0.0012	0.0009	0.0005	0.00019	0.0001	0.0001	0.0001
Casting sign 036										
Cast 2	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	99.996	0.0008	0.0004	0.0013	0.0008	0.0005	0.00019	0.0001	0.0001	0.0001
Casting sign 037										
Cast 3	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	99.997	0.0003	0.0004	0.0003	0.0003	0.0009	0.00011	0.0001	0.0001	0.0001
Casting sign 108										
Cast4	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	99.997	0.0007	0.0005	0.0003	0.0003	0.0006	0.00016	0.0001	0.0001	0.0001
Casting sign 609005										
Cast5	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	85.86516	14.10214	0.02777	0.00242	0.00188	0.00035	0.0001	0.00019	-	-
Casting sign 609006										
Cast 6	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	85.9281	14.04744	0.01976	0.00179	0.00224	0.00038	0.00012	0.00016	-	-
Casting sign 609007										
Cast 7	Zn	Al	Fe	Pb	Cu	Cd	Mg	Sn	As	Ti
	85.5884	14.37212	0.02821	0.00178	0.00839	0.00045	0.0001	0.0001	-	-

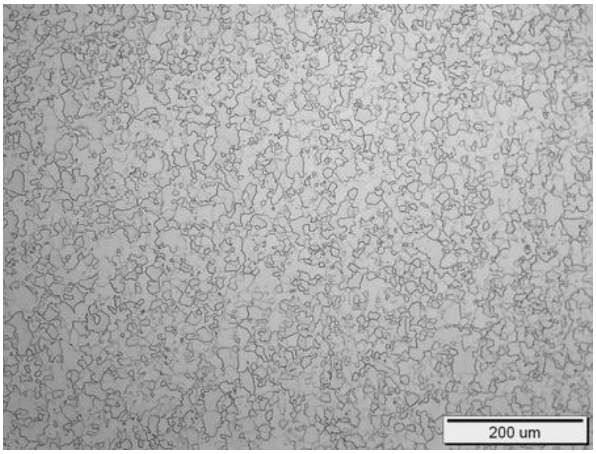

Fig. 1. Grained microstructure of the Zn alloy, casting 037

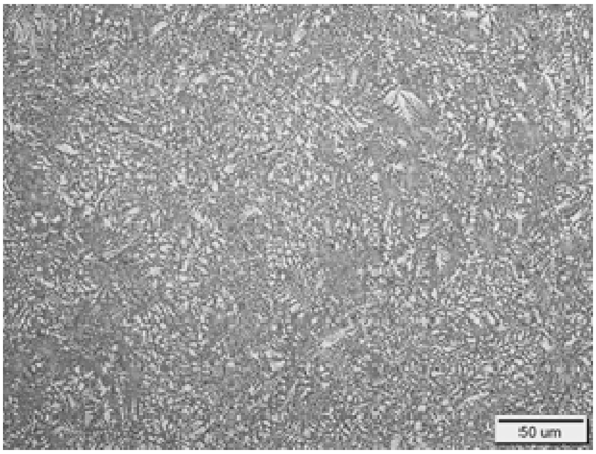

Fig. 2. Microstructure of the ZnAl15 alloy casting 609005-dendrites of the η solid solutions, eutectics (η+α)

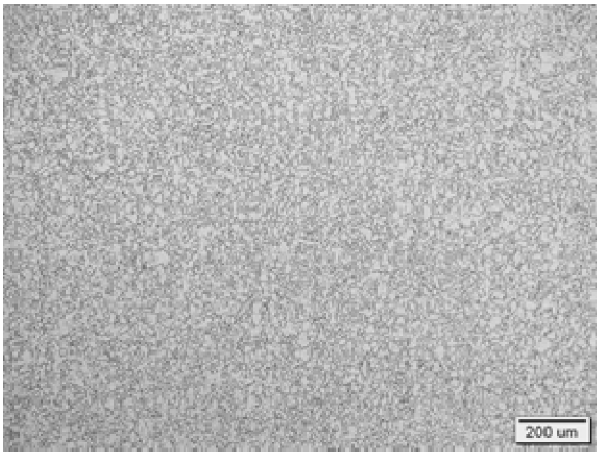

Fig. 3. Grained microstructure of the Zn alloy, casting 037

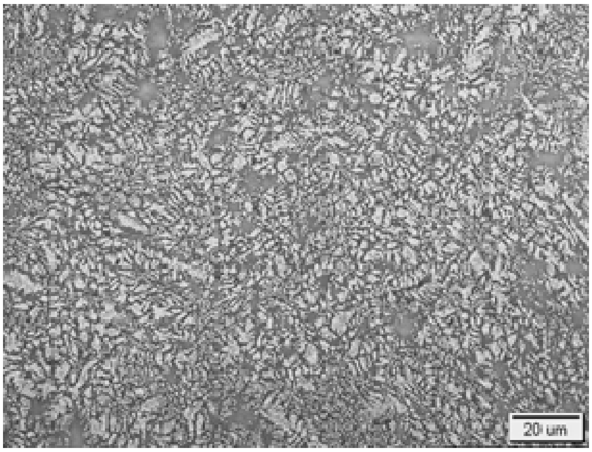

Fig. 4. Microstructure of the ZnAl15 alloy casting 609005-dendrites of the η solid solutions, eutectics (η+α)

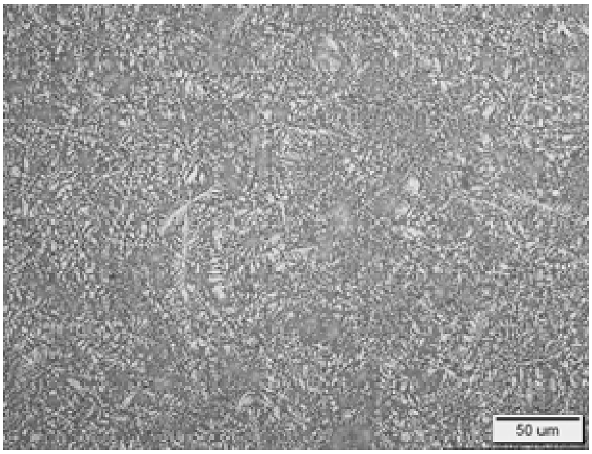

Fig. 5. Microstructure of the ZnAl15 alloy casting 609007-dendrites of the η solid solutions, eutectics (η+α)

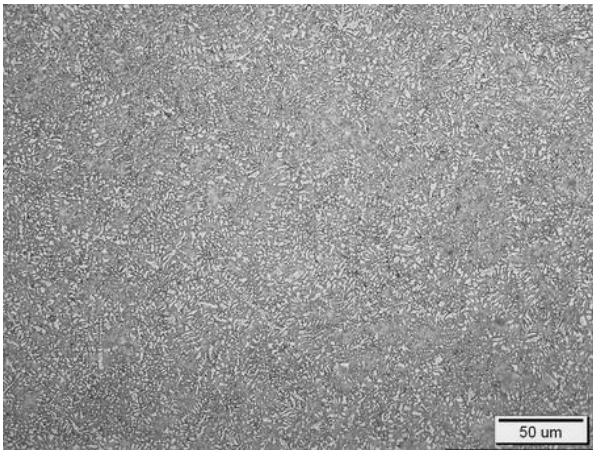

Fig. 6. Microstructure of the ZnAl15 alloy casting 609007-dendrites of the η solid solutions, eutectics (η+α)

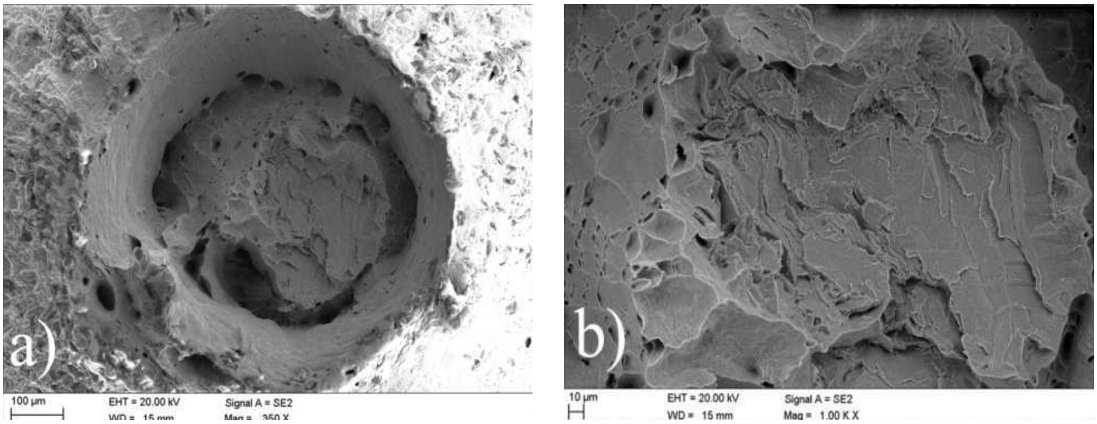

Fig. 7. Fracture of the Zn sample after strength test, casting 033, s) break in the areas of large elongation, b) mixed fracture with higher brittle fracture share

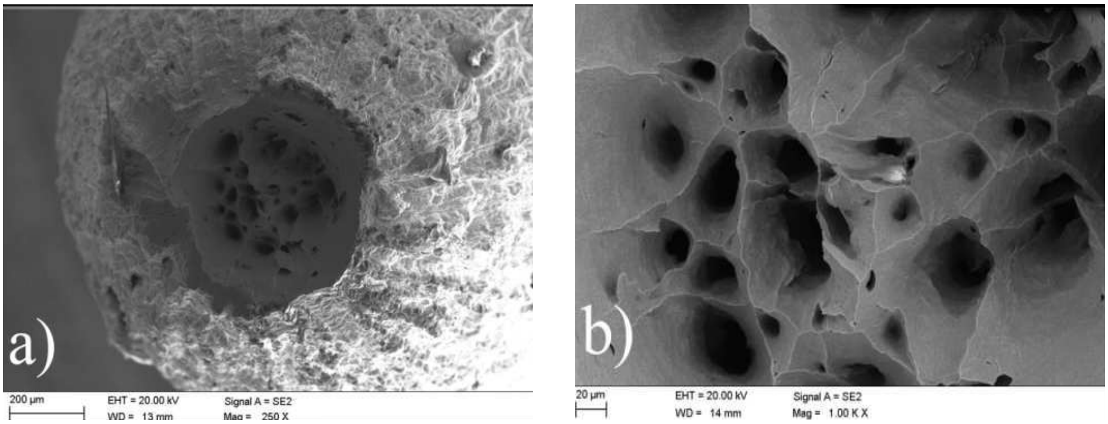

Fig. 8. Fracture of the Zn sample after strength test, casting 108, a) break in the areas of large elongation, b) mixed fracture with higher brittle fracture share

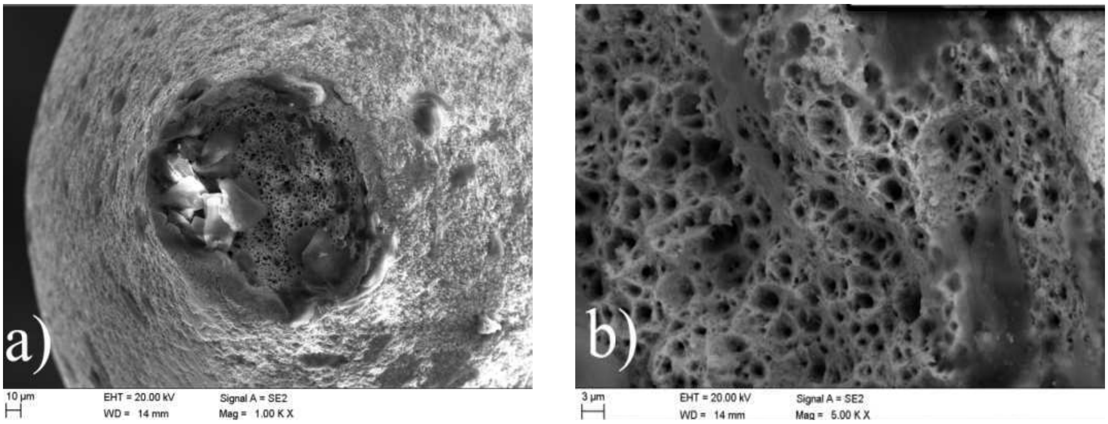

Fig. 9. Fracture of the Zn sample after strength test, 609006, a) break in the areas of large elongation, b) ductile fracture, craters on the break surface

Table 3.
Microhardness test results of the pure Zn

Casting	Average microhardness, HV 0.2	Standard deviation	Max value	Min value	Average error
033	41.2	0.3	42.7	40.2	0.62
036	40.9	0.39	42.5	39.0	1.05
037	35.9	0.26	36.9	34.7	0.41
108	39.3	0.15	39.9	38.6	0.14

Table 4.
Microhardness test results of the alloy ZnAl15

Casting	Average microhardness, HV 0.2	Standard deviation	Max value	Min value	Average error
609005	28.9	0.12	29.4	28.5	0.07
609006	27.2	0.87	29.1	23.5	3.42
609007	28	0.18	28.7	27.4	0.14
609007[1)]	40.2	0.08	40.5	39.8	0.04

4. Conclusions

The presented tests results carried out using light microscopy allowed the determination of the microstructures obtained after the production process of materials from pure zinc and selected zinc alloys. The observations made using the scanning electron microscope revealed that the decohesion after the static tensile strength test the investigated materials are characterized by a regular (circular) fracture. Pure zinc is characterized by the predominance of mixed fracture with the dominance of brittle fracture areas, whereas the zinc alloys reveals rather a ductile fracture. Based on the analysis of the chemical composition determined the chemical composition of the tested materials, stating their compliance with respect to the chemical composition included in the commercial standard [13-14]. The highest microhardness of the tested Zn and ZnAl15 reveals samples with the addition of Mg, Cu and Fe, further it was found that, in the tested Zn and Znal15 alloys there is a negative effect of Cd on the microhardness, revealing its decrease.

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