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Microstructures of Mg-Al-Zn and Al-Si-Cu cast alloys

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Methodology of research

ABSTRACT

Purpose: The aim of this paper was to investigate the structure of the MCMgAl6Zn1 magnesium and ACAlSi9Cu aluminium cast alloy in as-cast state.

Design/methodology/approach: The following results concern the microstructure of the cast magnesium and aluminium alloys using ZEISS SUPRA 25, Opton DSM-940 scanning and LEICA MEF4A light microscopy, X-ray qualitative microanalysis as well as X-ray analysis.

Findings: The analysis of the structure magnesium alloy consists of the solid solution α – Mg (matrix) of the secondary phase γ – Mg17Al12 evenly located in the structure. The structure creates agglomerates in the form of needle precipitations, partially coherent with the matrix placed mostly at the grain boundaries. The AC AlSi9Cu and AC AlSi9Cu4 cast aluminium alloys are characterised by a dendritic structure of the α solid solution - as the alloy matrix, as well are characterised by a discontinuous β–Si phase forming the $\alpha+\beta$ eutectic grains, with a morphology depending on the silicon and copper mass concentration.

Research limitations/implications: Taking into account the fact that some of the properties are of great importance only for the surface of the material, the future investigation will concern modelling of the alloy surface using surface layers deposition methods like physical vapour deposition methods.

Practical implications: A desire to create as light vehicle constructions as possible and connected low fuel consumption have made it possible to make use of magnesium and aluminium alloys as constructional material in automotive industry.

Originality/value: Contemporary materials should possess high mechanical properties, physical and chemical, as well as technological ones, to ensure long and reliable use. The above mentioned requirements and expectations regarding the contemporary materials are met by the non-ferrous metals alloys used nowadays, including the magnesium and aluminium alloys.

Keywords: Metallography; Magnesium alloys; Aluminium alloys, Structure

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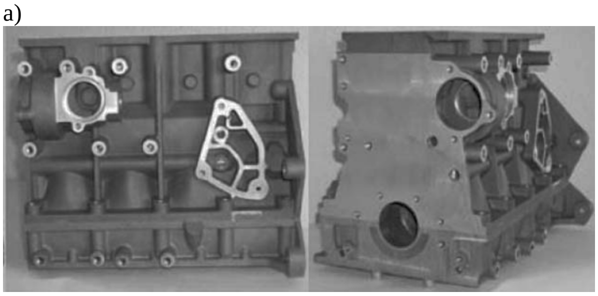
1. Introduction

Recent years' dynamic development, being present in the automobile industry, is mostly based on innovative constructional solutions as well modern materials, which directly influence mass, performances and fuel consumption. The most often pioneer solutions in the field of material engineering are just present in the automobile industry market – there are applied light, strength materials with big projecting potentials.

One of the basic groups of metal alloys, which allows for realisation of the early mentioned tasks are magnesium and aluminium alloys. Magnesium alloys are distinguished by a very useful technological parameter, namely the strength (yield strength $R_{p0.2}$) to density ratio. For the reason of a relative low value of the elasticity modulus magnesium alloys are characterised by a very good vibration dumping ability. Also for this reason these alloys are mainly used in sports equipment as well as application elements in the automotive industry. A huge advantage of the magnesium alloys is casting possibility of thin-walled large surface elements manufactured with high accuracy and dimensional stability. Moreover, magnesium alloys are characterised by extraordinary machinability, even at a low speed rate [1-4].

The demand for the magnesium cast alloys is mainly connected with development of the automotive industry (Fig. 1).

a)



b)

Fig. 1. Examples of automotive components made of Mg alloys a) engine block, b) oil pump

For example, *General Motors* in their big cars (Savana & Express) use 26.3 kg of magnesium cast alloys, and in smaller cars (Safari, Astro) – 165 kg, Ford F – 150 – 14.5 kg, VW Passat and Audi A4 and A6 from 13.6 to 14.5 kg, Alfa Romeo – 9.3kg. A further demand for magnesium casts is expected, of up to 50 kg per each car. It is mainly because of the fact that the magnesium casts have got a low density (1700-1900 kg/m3), and at the same time, their mechanical properties are similar to the aluminium casting alloys. Magnesium alloys have got good casting properties and the possible shrinkage porosities or hot micro-cracks can be counteracted by applying alloy additions. By choosing the alloy additions, the mechanical properties or corrosion resistance can be influenced [5-9].

Thanks to the introduction of new technologies the costs of processing could be lowered and, above all, the casting methods have been improved. The ways of making elements out of partly crystallized magnesium alloys, moulding in a liquid and solid-liquid state, vacuum casting, pressure die casting on cold- and hot-chamber machines have been worked out. A general tendency of a present stage of cast materials development is the increase of their plasticity together with the increase of their resistance properties.

Aluminium alloys are the second group of light materials used in the automotive and aviation industry. Great popularity of the aluminium alloys in these industry branches is connected to their general functional properties, namely their low density of 2689 kg/m^3, good mechanical properties, good corrosion resistance as well as very good machinability [11-12]. These properties are the reason to be applied in car and aircraft engine bodies, housings of: gearboxes, clutches, water pumps and rear axles, making it possible to decrease the operating expenses as well as decrease fuel consumption, connected with – combustion gas emission into the air. Last years, together with the automobile industry development and pursuing the energy-consuming reduction of the production processes there are tendencies emerging to go back to aluminium alloy sand casting performed using high- efficiency automated production lines. Examples of such solutions are very often used technologies like: Cosworth, CPS, BAXI or HWS. These technologies assure very good form filling ability under high pressure and reduction of oxidation of the applied aluminium alloys [13-15].

The goal of this paper is to present the investigation results of the MCMgAl9Zn1, MCMgAl6Zn1, ACAlSi9Cu, ACAlSi9Cu4 casting magnesium and aluminium alloys in its as-cast state.

2. Experimental procedure

The investigations have been carried out on test samples of MCMgAl9Zn1, MCMgAl6Zn1 magnesium alloys and ACAlSi9Cu, ACAlSi9Cu4 aluminium alloys in as-cast. The chemical composition of the investigated materials is given in Table 1, 2.

Metallographic examinations have been made on cast alloy specimens mounted in thermohardening resins. In order to disclose grain boundaries and microstructure and also to distinguish precisely the particular precipitations in investigation alloys as an etching reagent, 5% molybdenic acid and 1% HBF_4 acid have been used. The time of etching for each specimen was between 5-10 s. The observations of the investigated cast materials have been made on the light microscope LEICA MEF4A as well as on the electron scanning microscope Opton DSM-940 and ZEISS SUPRA 25 using the secondary electron detection. The X-ray qualitative and quantitative microanalysis and the analysis of a surface distribution of cast elements in the examined magnesium cast alloy specimens in as-cast and after heat treatment have been made on transverse microsections on the ZEISS SUPRA 25 and Opton DSM-940 scanning microscope with the Oxford EDS LINK ISIS dispersive radiation spectrometer at the accelerating voltage of 15 kV and on the JEOL JCXA 733 x-ray microanalyser.

Table 1
Chemical composition of magnesium alloys

Alloy type	The mass concentration of the main elements, %						
	Al	Zn	Mn	Si	Fe	Mg	Rest
MCMgAl9Zn1	9.09	0.77	0.21	0.037	0.011	89.7905	0.0915
MCMgAl6Zn1	5.92	0.49	0.15	0.037	0.007	93.3347	0.0613

Table 2
Chemical composition of aluminium alloys

Alloy type	The mass concentration of the main elements, %								
	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al	Rest
ACAlSi9Cu	9.09	0.72	1.05	0.36	0.27	0.14	0.07	88.17	0.08
ACAlSi9Cu4	9.27	0.17	4.64	0.01	0.28	0.05	0.09	85.4	0.09

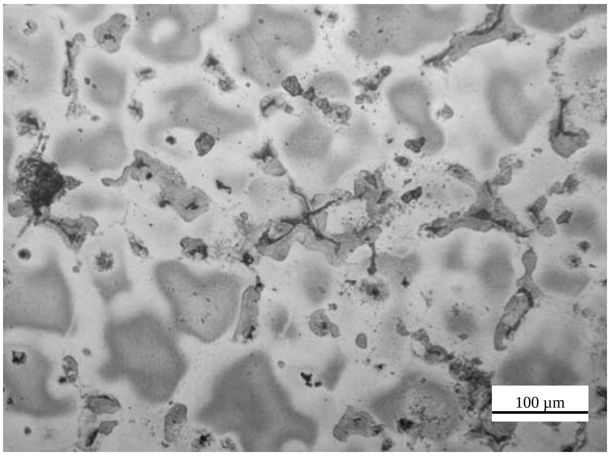
3. Discussion of results

3.1. Magnesium alloys

As a result of metallographic investigations made on the light and scanning microscopes it has been confirmed that the magnesium cast alloys MCMgAl9Zn1 in the cast state are characterized by a microstructure of the solid solution α constituting the alloy matrix as well as the $\gamma - Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries (Fig. 2, 3). Moreover, in the vicinity of the γ intermetallic phase precipitations the presence of the needle eutectics (α + γ) has been revealed (Fig. 2, 3). In the structure of the examined magnesium cast alloys one can observe, apart from $Mg_{17}Al_{12}$ precipitations, turning grey-green phases, characterized by angular contour with smooth edges in the shape of hexahedrons. Out of the chemical composition examinations with the use of the EDS dispersive radiation spectrometer as well as literature data, one can conclude that it is the Mg_2Si compound which, when precipitating, increases the hardness of castings (Fig. 2b, 3b).

As a result of the surface decomposition of elements and the x-ray, quantitative micro analysis made using the EDS energy dispersive radiation spectrometer, the presence of the main alloy additions Mg, Al, Mn, Zn and also Fe and Si included in the magnesium cast alloys in as-cast and has been confirmed (Fig. 4). The information about a mass and atom concentration of particular elements in the pointwise examined micro locations of matrix and precipitations. The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections of the magnesium alloys using the EDS system have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours in the alloy structure as well as phases with high Mn and Al concentrations that are irregular with a non plain surface, often occurring in the forms of blocks or needles (Fig. 4). Because the size of particular elements of the structure is, in a prevailing measure, smaller than the diameter of the analyzing beam, the obtained at the quantitative analysis chemical composition may be averaged as a result of which some values of element concentrations may be overestimated. A prevailing participation of magnesium and aluminium and a slight concentration of Zn have been ascertained in the alloy matrix as well as in the location of eutectics and big precipitations that arouse at phase boundaries identified as $Mg_{17}Al_{12}$.

a)



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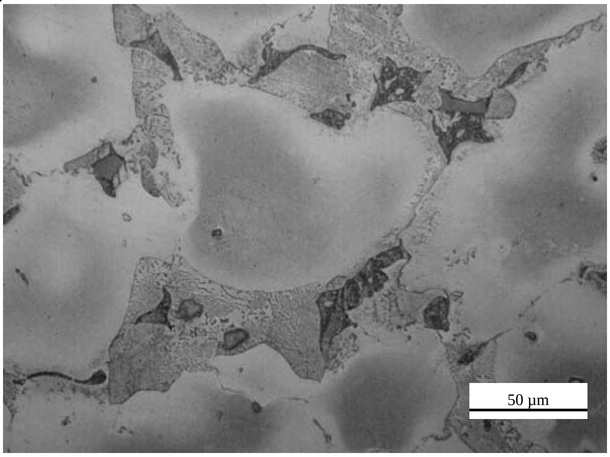


Fig. 2. a), b) Microstructure of MCMgAl6Zn1 magnesium alloys in as-cast state

a) b)

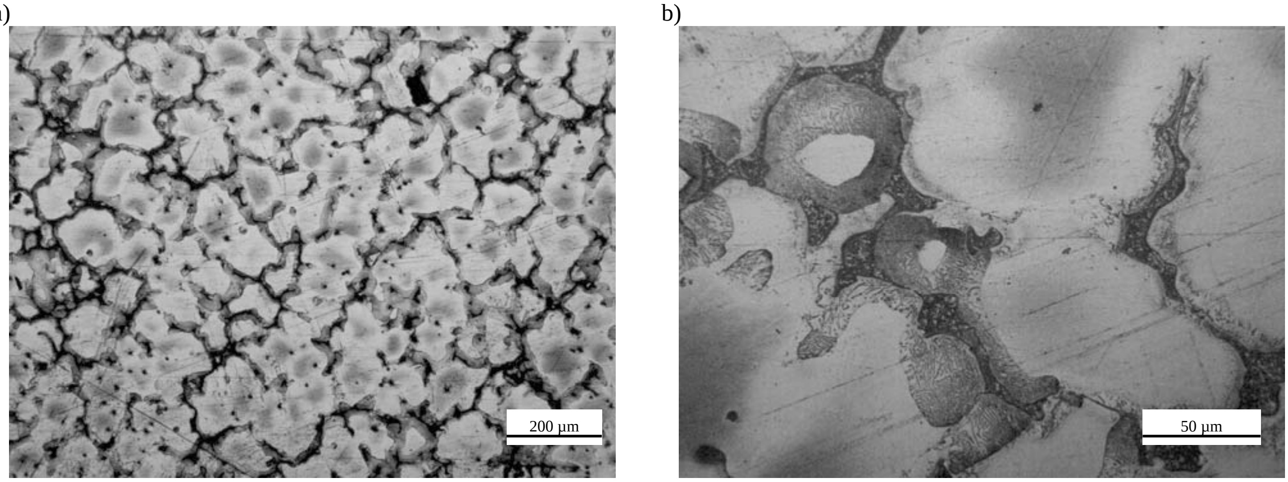


Fig. 3. a), b) Microstructure of MCMgAl9Zn1 magnesium alloys in as-cast state

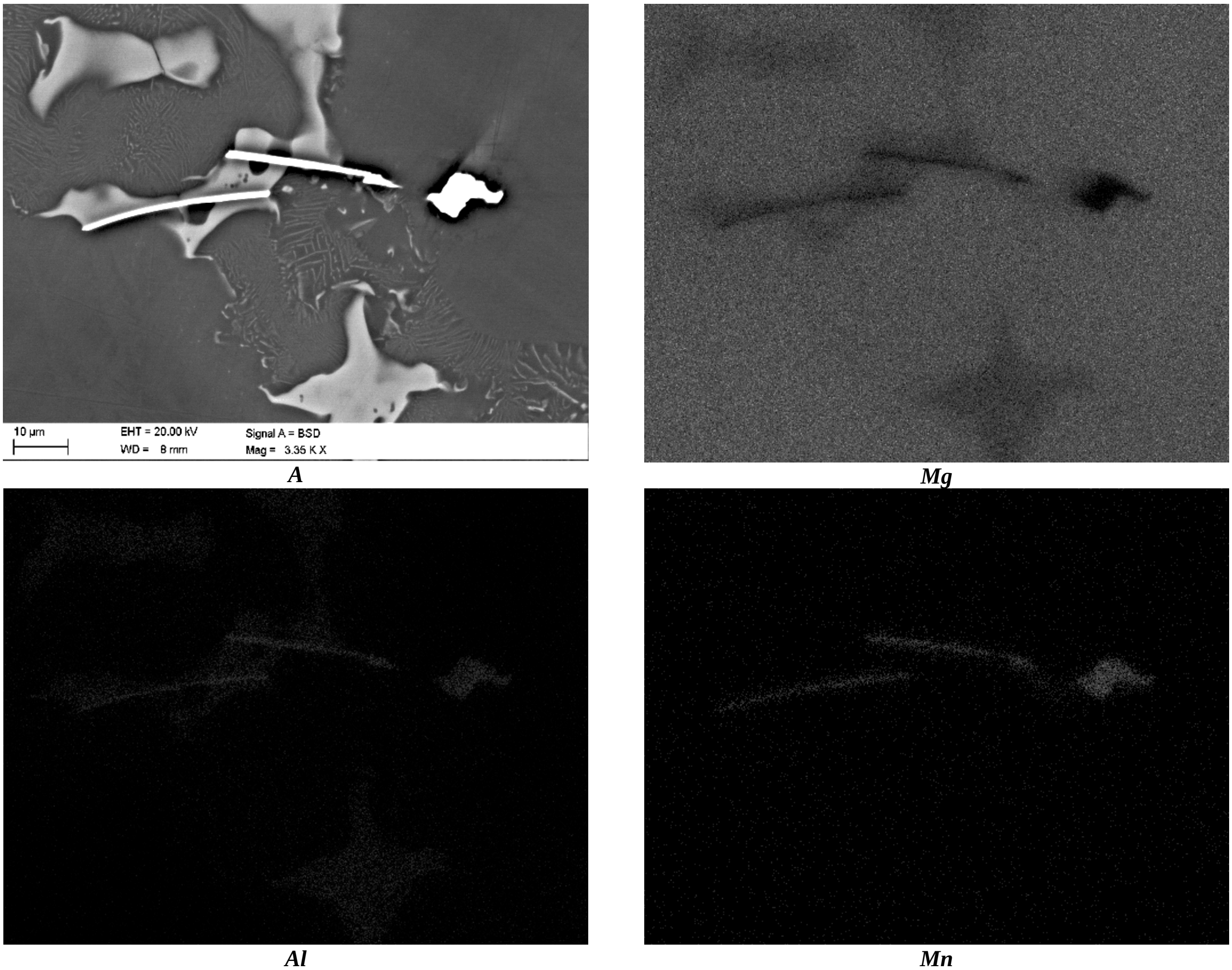
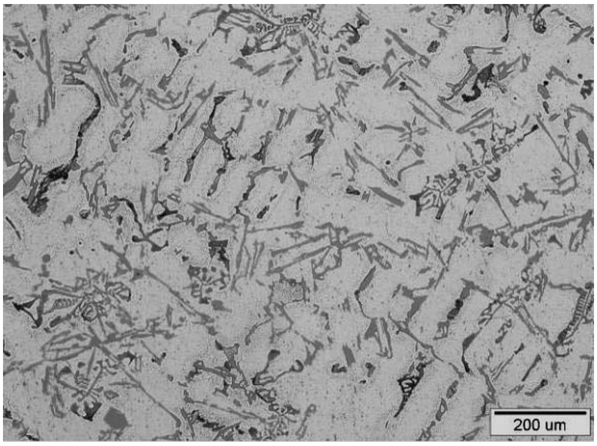


Fig. 4. The area analysis of chemical elements alloy MCMgAl6Zn1 in as-cast state: image of the secondary electrons (A) and maps of elements' distribution

3.2. Aluminium alloys

The results of the metallographic investigations performed on the optical microscope show that the ACAlSi9Cu and ACAlSi9Cu4 cast aluminium alloys are characterised by a dendritic structure of the α solid solution - as the alloy matrix, as well are characterised by a discontinuous β–Si phase forming the α+β eutectic grains, with a morphology depending on the silicon and copper mass concentration (Figs. 5-7).

a)



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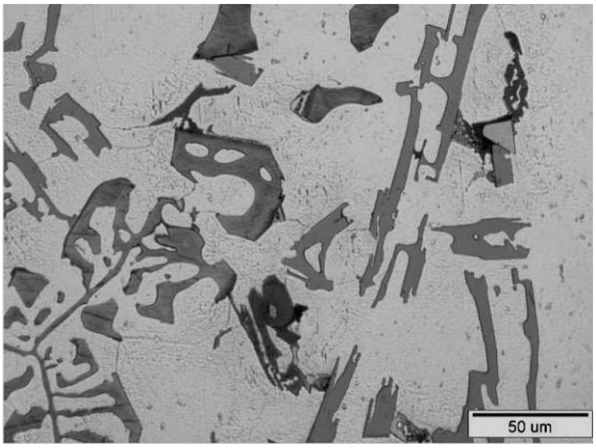

Fig. 5. a), b) Microstructure of ACAlSi9Cu casting alloy

The ACAlSi9Cu and ACAlSi9Cu4 alloys are characterised by the β–Si phase occurred in the form of big irregular plates with sharply ending corners placed in the matrix in a disordered manner, they are also characterised by a big interphase distance (Fig. 5 and 6).

Also the occurrence of the $\alpha+Al_2Cu+\beta$ and $\alpha+Al_2Cu+AlCuMgSi+\beta$ eutectics was state in the investigated alloys, which confirm also following literature sources [16, 17]. Moreover, the microstructure of the investigated alloys is characterised by the occurrence of needle-shaped precipitations of the Al_5FeSi phase, which usually occurs near the $\alpha+Al_2Cu+AlCuMgSi+\beta$ eutectics (Fig. 6).

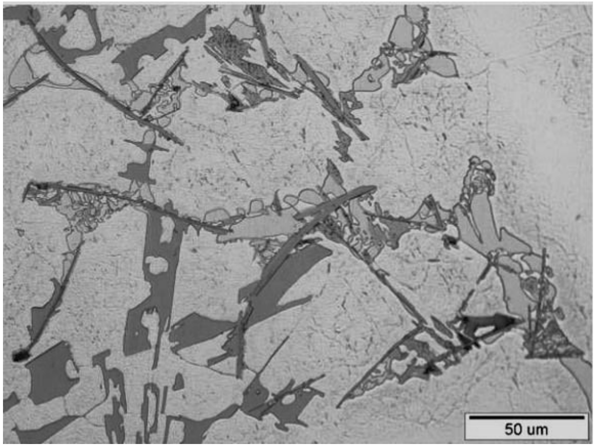

Fig. 6. Microstructure of ACAlSi9Cu4 casting alloy

The Al_2Cu phase occurs in the investigated cast Al–Si–Cu alloys as a compound of the triple eutectic as well as a separate, irregular shaped, brown coloured precipitate, of the Chinese character type (Fig. 7).

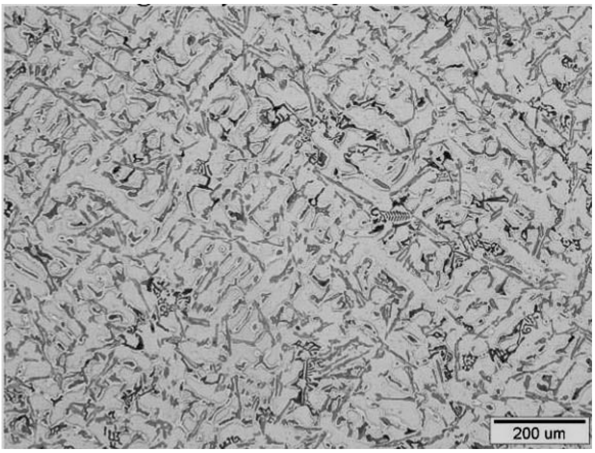

Fig. 7. Microstructure of ACAlSi9Cu4 casting alloy

As a result of the performed investigations using the quantitative EDS analysis, the occurrence of the basic alloying additives Si, Cu, Mg, as well Fe was confirmed - as the main compound of the Al–Si–Cu alloys. Information was obtaining also about the atomic and mass concentration of particular elements in the investigated microareas and precipitations using the point-wise EDS analysis (Fig. 8). As a result of the preformed analyses it was state that copper, silicon and magnesium occur in bigger concentrations into the eutectic regions, as well in the alloy matrix. The microstructure observations and EDS microanalysis confirm the occurrence of α+β eutectics (Fig. 9) in the investigated alloys. It can be state, that in the investigated alloys there are also triple α+Al2Cu+β eutectics present (Fig. 8).

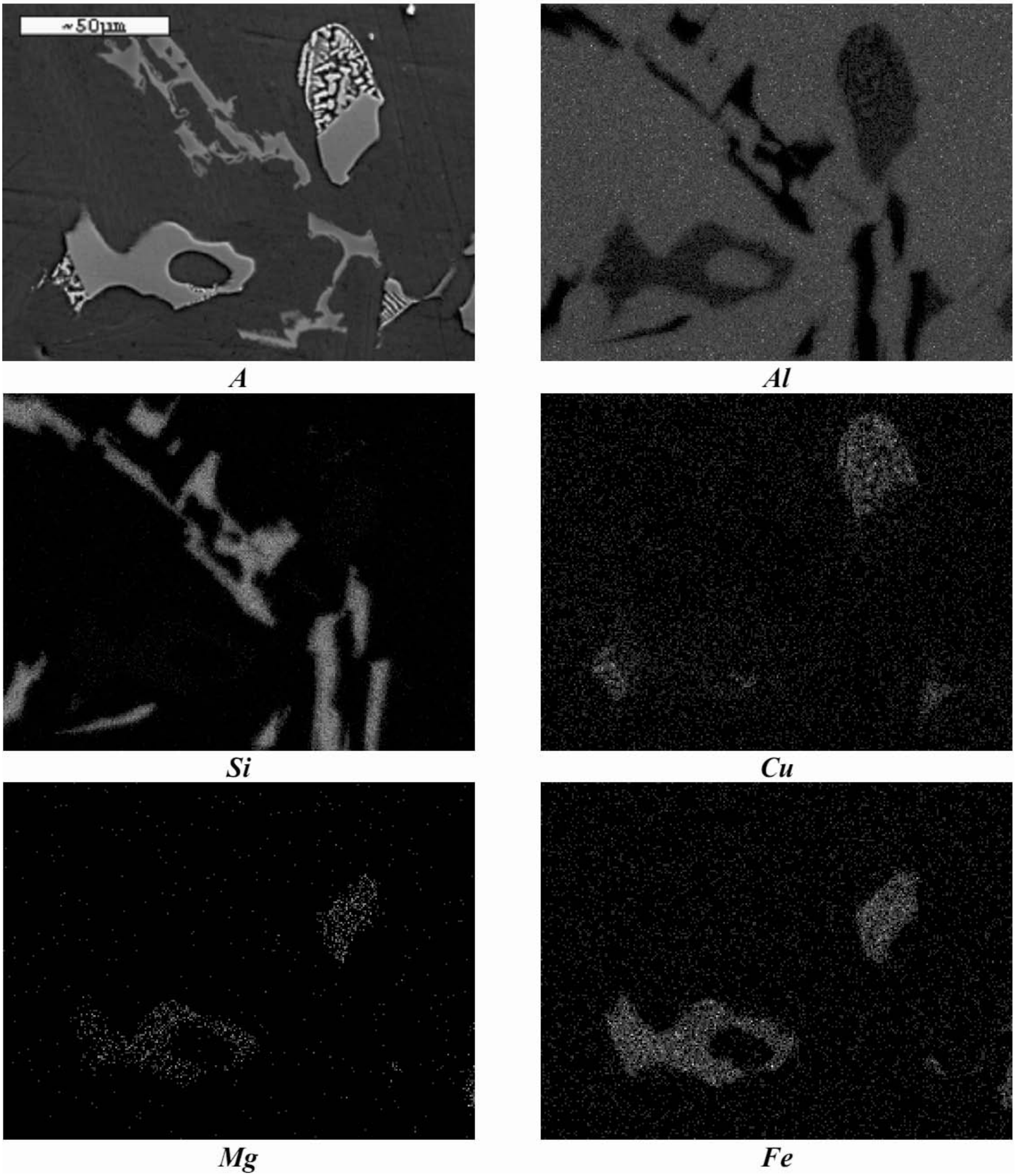

Fig. 8. The area analysis of chemical elements alloy ACAlSi9Cu4: image of secondary electrons (A) and maps of elements' distribution

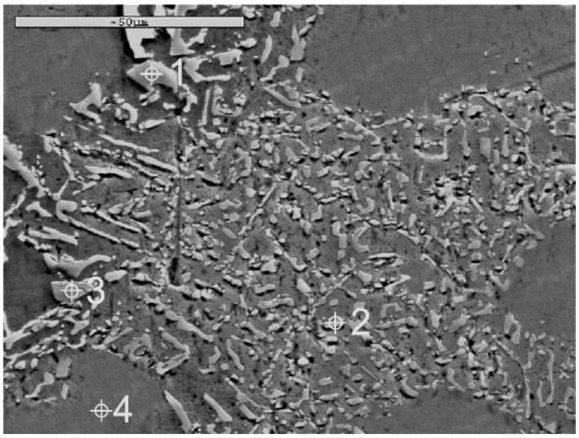

Fig. 9. Microstructure of ACAlSi9Cu casting alloys

Table 3
Pointwise chemical composition analysis of the aluminium casting alloys ACAlSi9Cu

Chemical element	The mass and atomic concentration of main elements, %	
	mass	atomic
	Analysis 1 (point 1)	
Al	0.20	0.10
Si	99.04	99.56
Cu	0.72	0.32
Rest	0.04	0.02
	Analysis 2 (point 2)	
Al	45.03	46.19
Si	54.33	53.53
Cu	0.64	0.28
	Analysis 3 (point 3)	
Al	25.08	25.9
Si	74.53	73.93
Cu	0.37	0.16
Rest	0.02	0.01
	Analysis 4 (point 4)	
Al	97.24	98.02
Si	1.52	1.47
Cu	1.14	0.49
Mg	0.02	0.01
Fe	0.08	0.01

4. Summary

The results of the metallographic examinations made on the light and scanning microscopes confirm the fact that the magnesium cast alloy MCMgAl9Zn1 is characterized by a microstructure of the solid solution α constituting the alloy matrix as well as the $\gamma - Mg_{17}Al_{12}$ discontinuous intermetallic phase in the forms of plates located mostly at grain boundaries. Moreover, in the vicinity of the γ intermetallic phase precipitations the presence of the needle eutectics $(\alpha + \gamma)$ has been revealed.

The chemical analysis of the surface element decomposition and the quantitative micro analysis made on the transverse microsections have also confirmed the evident concentrations of magnesium, silicon, aluminium, manganese and iron what suggests the occurrence of precipitations containing Mg and Si with angular contours, as well as phases with high Mn and Al concentrations that are irregular, with a non plain surface, often occurring in the forms of blocks or needles.

The results of the metallographic investigations performed on the optical and scanning microscope show, that the ACAlSi9Cu and ACAlSi9Cu4 cast aluminium alloys are characterised by a dendritic structure of the α solid solution - as the alloy matrix, as well are characterised by a discontinuous β–Si phase occurred in form of big irregular plates with sharply ending corners placed in the matrix in a disordered manner, they are also characterised by a big interphase distance, forming the α+β eutectic grains. Also the occurrence of the $\alpha+Al_2Cu+\beta$, $\alpha+Al_2Cu+AlCuMgSi+\beta$ eutectics Al_5FeSi phase which usually occurs near the α+Al_2Cu+AlCuMgSi+β eutectics was state in the investigated alloys.

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