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Investigation of the MCMgAl12Zn1 magnesium alloys structure after heat treatment

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Materials

ABSTRACT

Purpose: Main aim of this paper is to describe the structure of the MCMgAl12Zn1 magnesium cast alloy as-cast state and after a heat treatment.
Design/methodology/approach: The following results concern metallographic examinations, the X-ray qualitative and quantitative microanalysis, X-ray diffraction method.
Findings: The different heat treatment kinds employed contributed to the improvement of mechanical properties of the alloy with the slight reduction of its plastic properties.
Research limitations/implications: According to the alloys characteristic, the applied cooling rate and alloy additions seems to be a good compromise for microstructures, nevertheless further tests should be carried out in order to examine different cooling rates and parameters of solution treatment process and aging process.
Practical implications: The concrete examples of the employment of castings from magnesium alloys in the automotive industry are elements of the pedals, dashboards, elements of seats, steering wheels, wheel bands, oil sumps, elements and housings of the gearbox, framing of doors and sunroofs, and others, etc.
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 alloys.
Keywords: Heat Treatment; Magnesium alloys

1. Introduction

The magnesium alloys are, apart from the titanium alloys, a very modern and of good quality material for manufacturing different machine elements and devices. Hence, the increasing interest in magnesium, also in the cognitive area, can be observed, supported by the fact of organizing big world conferences on this subject [1-4, 8, 9].

The greatest part of the manufactured magnesium is being used as an additin or a microaddition to the ferrous alloy or the nonferrous alloys. However, almost one third of the world's production of magnesium is mainly meant for manufacturing magnesium alloys as pressure castings. According to the statistics of Hydro Magnesium company, the production of the magnesium cast alloys was increasing in the years 1993-2003 in the parabolic course, up to almost 180 000 tons, and Europe significantly contributed to this increase with its 80 000 tons. The demand for the magnesium cast alloys is mainly connected with the development of the automotive industry. 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 – 9.3 kg. 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/m^3), 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 [1, 4, 5-14].

Magnesium alloys have also found their application in manufacturing of mowers, saws, robots, office equipment including computer hardware, sport and medical appliances, in production of movie and video cameras, for rocket parts, space ships, and others (Fig. 1) [1-17].

The growing trends in the production of magnesium alloys point at the increased necessity of their application in the world constructional industry, and the magnesium alloys will become one of the most frequent materials used in the following decades. Hence, it is so extremely important to maintain a high pace of the research over the issue of the light alloys, including also that done in the Division of Materials Processing Technology, Management and Computer Techniques, in Materials Science of the Institute of Engineering Materials and Biomaterials of Silesian University of Technology.

The goal of this paper is presentation of the investigation results of the MCMgAl12Zn1 casting magnesium alloy in its as-cast state and after heat treatment.

2. Experimental procedure

The investigations have been carried out on test pieces of MCMgAl12Zn1 magnesium alloys in as-cast and after heat treatment states (Table 2) made in cooperation with the Faculty of Metallurgy and Materials Engineering of the Technical University of Ostrava and the CKD Motory plant, Hradec Kralove in the Czech Republic. The chemical composition of the investigated materials is given in Table 1. A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath Flux 12 equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. In order to maintain a metallurgical purity of the melting metal, a refining with a neutral gas with the industrial name of Emgesalem Flux 12 has been carried out. To improve the quality of a metal surface a protective layer Alkon M62 has been applied. The material has been cast in dies with betonite binder because of its excellent sorption properties and shaped into plates of 250x150x25. The cast alloys have been heated in an electrical vacuum furnace Classic 0816 Vak in a protective argon atmosphere.

Metallographic examinations have been made on magnesium cast alloy specimens mounted in thermohardening resins. In order to disclose grain boundaries and the structure and to distinguish precisely the particular precipitaions in magnesium alloys as an etching reagent a 5% molybdenic acid has been used. The time of the 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 at magnification 500x as well as on the electron scanning microscope Opton DSM-940 using a 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 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 microanalizer.

Phase composition and crystallographic structure were determined by the X-ray diffraction method using the XPert device with a copper lamp, with 40 kV voltage. The measurement was performed by The X-ray quantitative analysis has been made using the Rietveld method and the Xpert Plus program. The analysis was based on matching the tiniest squares of the theoretically determined diffraction pattern to the one obtained through the measurement, together with the simultaneous allowance for matching the crystallographic structure, the diffraction geometry effects, apparatus factors and the properties of the examined material. The phase analysis carried out in the Rietveld method using the matching parameters was based on the Hill and Howard interrelation, where:

$$W_p = \frac{s_p(ZMV)_p}{\sum_{i=0}^{n} s_i(ZMV)_i} \tag{1}$$

Wp – mass fraction of the p phase in the n phases mixture,
s – scale factor,
Z – number of molecules falling on the volume of the unit cell,
M – mass of the particle,
V – unit cell volume

3. Discussion of experimental results

The results of the metallographical examinations done on the light and scanning microscopes, as well as those based on the analyses of the surface decomposition of elements, the X-ray magnesium casting alloys in as-cast state show a microstructure of a solid solution α constituting a matrix as well as the intermetallic phase $\gamma - Mg_{17}Al_{12}$ in the plate form, placed mainly at the grain boundaries (Fig. 2, 3, 4a).

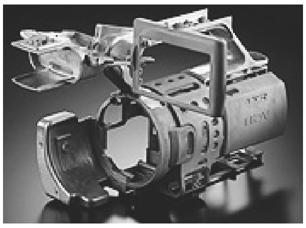
Moreover, near the γ intermetallic phase precipitations, the presence of the needle eutectics (α+γ) has been ascertained. In the structure of the examined magnesium cast alloys one can, apart from the $Mg_{17}Al_{12}$ phase precipitations, also observe turning grey phases characterized by angular contours with smooth edges in the form of hexagonal particles. Out of the chemical composition when using the X-ray scattered radiation spectrometer EDS as well

Mobile phone

Housing of the lock

Wheel bands

Steering wheels



Housing of the camera

Bicycle accessories

ski binding

Fig. 1. Elements from magnesium alloys [1-17]

Table 1.
Chemical composition of investigation alloy

The mass concentration of main elements, %						
Al	Zn	Mn	Si	Fe	Mg	Rest
12,1	0,617	0,174	0,0468	0,0130	86,9507	0,0985

Table 2.
Parameters of heat treatment of investigation alloy

Sing the state of heat treatment	Solution treatment			Aging treatment		
	Temperature	Time	Cooling	Temperature	Time	Cooling
0	As-cast					
1	430	10	water	-	-	-
2	430	10	water	190	15	air

as literature data, one can conclude that it is the Mg_2Si phase, which, when precipitating, increases the hardenability of the casts. Numerous areas of non-dissolved in the solid solution γ phase and eutectics have been observed after the solution heat treatment with cooling in water in MCMgAl12Zn1 cast (Fig. 4b). The applied quench ageing in water with air cooling, causes the precipitation of evenly spread dyspersion particles of $Mg_{17}Al_{12}$ phase, occuring also in the form of pseudoeutectic areas (as pseudoeutectic areas was meant the structure created as the result γ phase precipitation out of the solid solution during the cast ageing previolsy supersaturated with water cooling, showing the morphology close to the eutectics formed out of the liquid phase) (Fig. 3, 4c, 5).

As a result of the carried out examinations of the surface decomposition of elements and the X-ray quantitative microanalysis performed with the use of the X-ray dispersive radiation spectrometer, the presence of the main Al, Mn, Zn, Fe and Si alloy additions has been confirmed, which are part of the magnesium cast alloys in as-cast and after the heat treatment (Fig. 3, 5, Table 3).

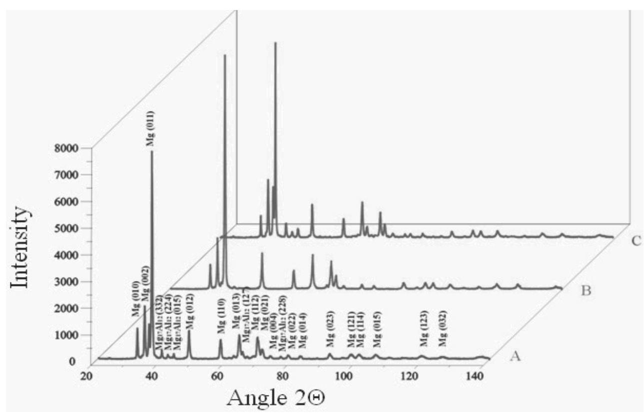


Fig. 2. Qualitative XRD patterns of the magnesium casting alloys MCMgAl12Zn1: A–without heat treatment, B–after solution treatment with cooling in the water, C–after aging treatment

The information about the mass and atom concentration of particular elements has also been obtained, in the point examined microareas of the matrix and precipitations. Alike in the alloy matrix as well as in the eutectic area and big precipitations on the borders of phases identified as $Mg_{17}Al_{12}$, a prevailing pariticipation of magnesium and aluminium has been asscertained, together with a low concentration of Zn. The chemical analysis of the surface decomposition of elements as well as the quantitative microanalysis made on the transverse microsections with the use of the EDS system, have shown, in some regions, a significant concentration of magnesium, silicon, aluminium, manganese and iron, what suggests the occurence of precipitations containing Mg and Si with angular contours, and also phases with high Mn and Al concentrations, which are irregular in shape and often occur in the form of blocks or needles. Because the size of the particular structure elements is smaller than the diameter of the analyzing beam, the obtained, at the quantitative analysis, chemical composition may be averaged, as the result of which, some elements' concentration values can be overestimated.

It has been confirmed, on the basis of the examinations of the X-ray quantitative analysis, that the volume of the β phase precipitations in the structure of the examined alloys, accepts its maximum 11.9% value for the MCMgAl12Zn1 alloy in after-ageing state (Fig. 6).

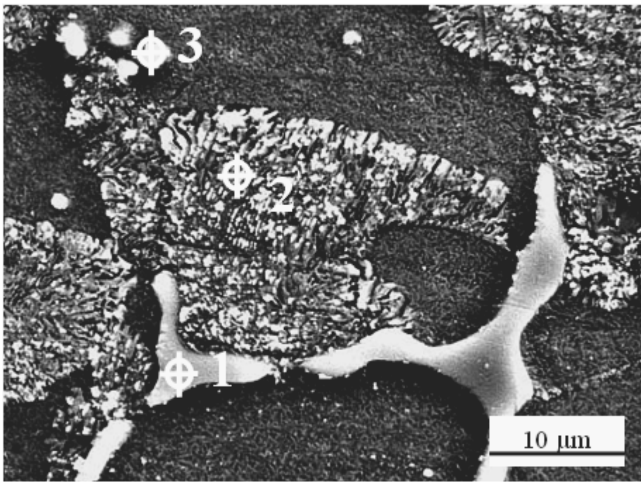


Fig. 3. The X-ray quantitative microanalysis alloy MCMgAl12Zn1, after aging treatment

Table 3.
Pointwise chemical composition analysis of the magnesium casting alloys MCMgAl12Zn1 after aging treatment

Chemical element	The mass concentration of main elements, %	
	mass	atomic
Analysis 1 (point 1)		
Mg	64.82	67.90
Al	33.18	31.31
Zn	1.94	0.76
rest	0.06	0.03
Analysis 2 (point 2)		
Mg	85.61	88.32
Al	12.85	11.41
Zn	0.64	0.23
rest	0.90	0.04
Analysis 3 (point 3)		
Al	54.29	70.44
Mn	39.73	25.32
Fe	3.81	2.39
rest	2.17	1.85

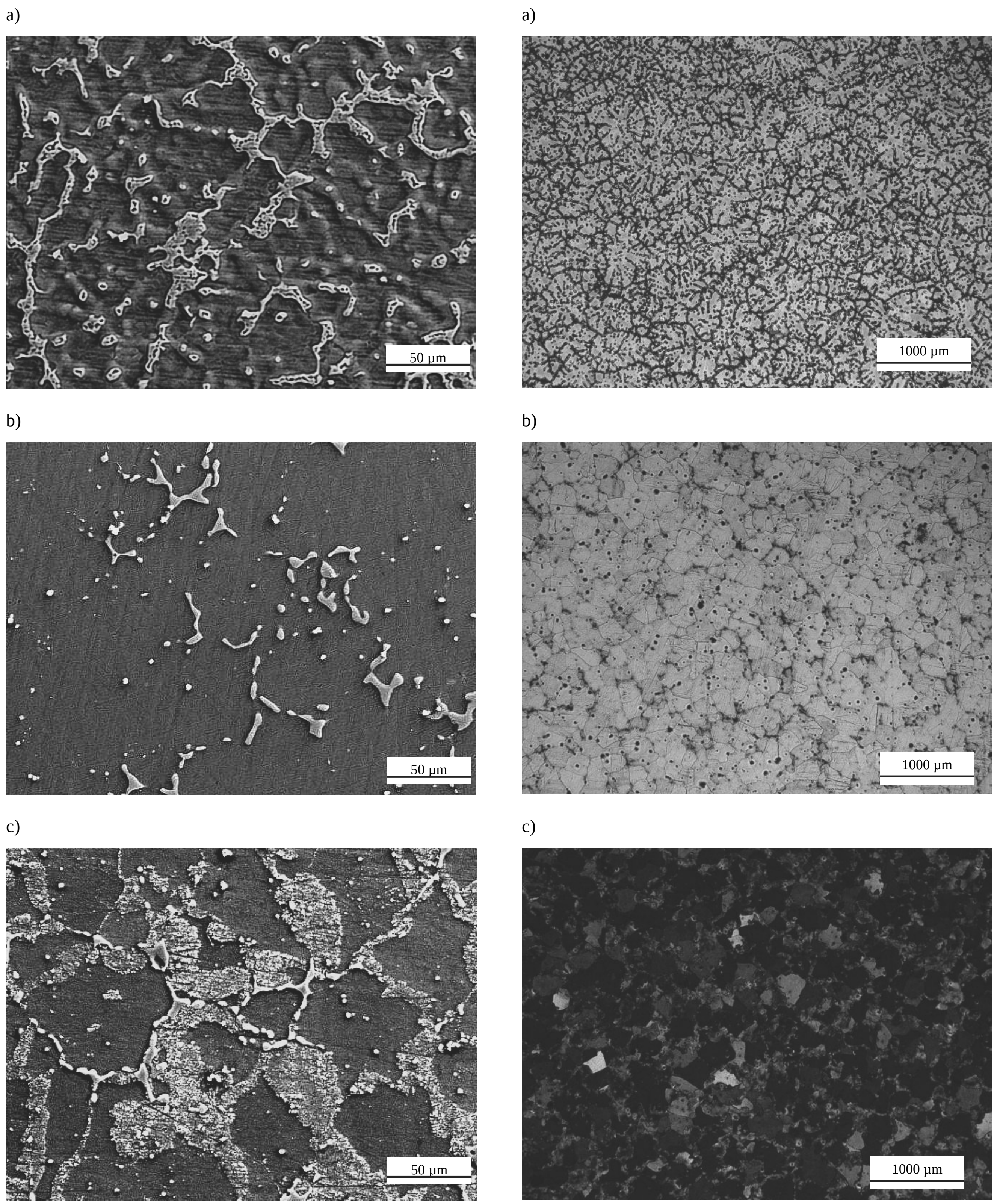


Fig. 4. Microstructure alloy MCMgAl12Zn1: a) without heat treatment, b) after cooling in the water, c) after aging treatment

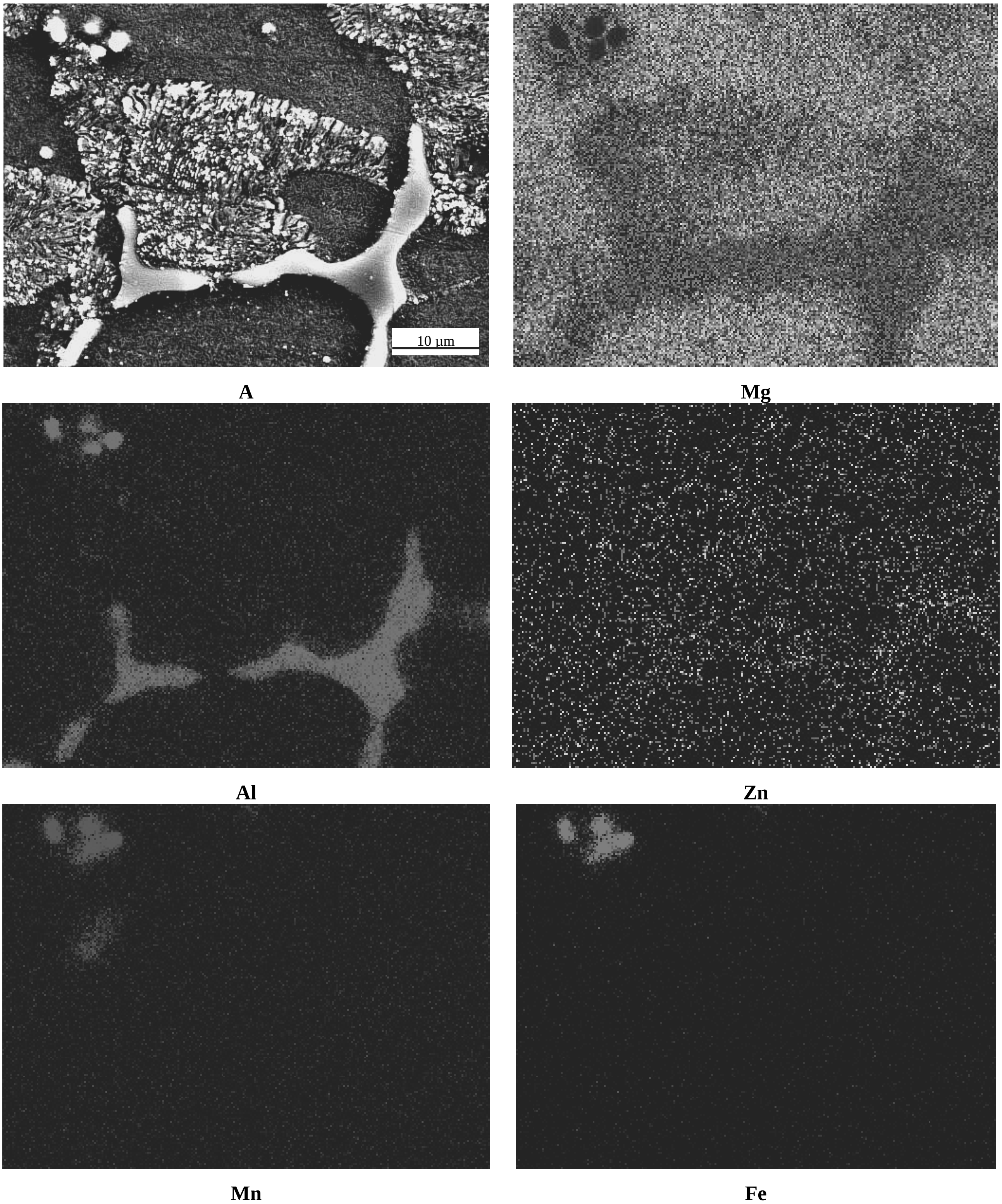


Fig. 5. The area analysis of chemical elements alloy MCMgAl12Zn1 after aging treatment: image of secondary electrons (A) and maps of elements' distribution

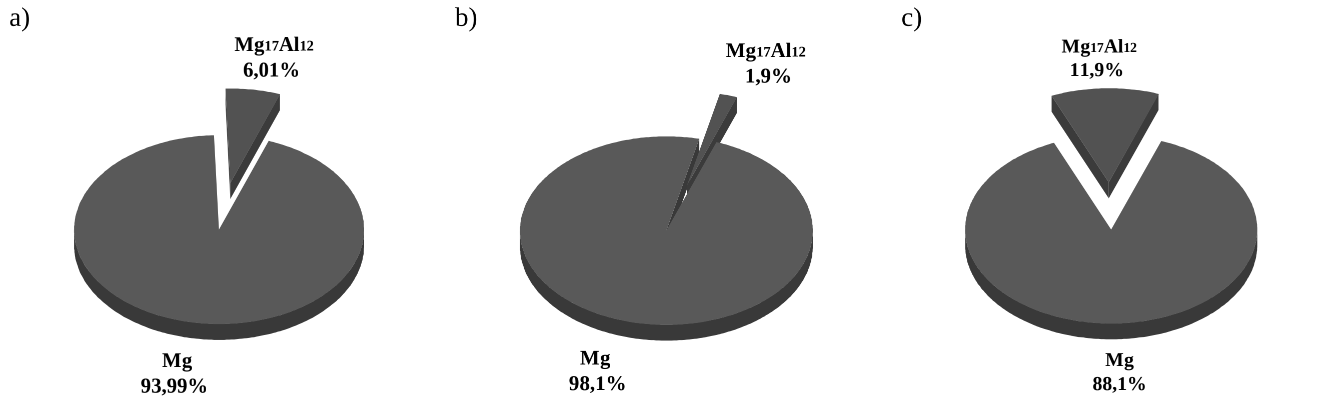


Fig. 6. Quantitative XRD patterns of the magnesium casting alloys MCMgAl12Zn1: a) without heat treatment, b) after solution treatment with cooling in the water, c) after aging treatment

4. Conclusions

The results of the metallographical examinations done on the light and scanning microscopes, as well as those based on the analyses of the surface decomposition of elements, the X-ray magnesium casting alloys show a microstructure of a solid solution α constituting a matrix as well as the intermetallic phase γ – $Mg_{17}Al_{12}$ in the plate form, placed mainly at the grain boundaries (Figs. 2, 4, 6). Moreover, near the γ intermetallic phase precipitations, the presence of the needle eutectics (α+γ) has been ascertained. The chemical analysis of the surface decomposition of elements as well as the quantitative microanalysis made on the transverse microsections with the use of the EDS system, have shown, in some regions, a significant concentration of magnesium, silicon, aluminium, manganese and iron, what suggests the occurence of precipitations containing Mg and Si with angular contours, and also phases with high Mn and Al concentrations, which are irregular in shape and often occur in the form of blocks or needles (Fig. 5).

It has been confirmed, on the basis of the examinations of the X-ray quantitative analysis, that the volume of the β phase precipitations in the structure of the examined alloys, accepts its maximum 11.9% value for the MCMgAl12Zn1 alloy in after-ageing state (Fig. 6).

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