Archives of Materials Science and Engineering

Volume 36
Issue 1
March 2009
Pages 48-54

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

The influence of the heat treatment on the microstructure and properties of Mg-Al-Zn based alloys

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Received 12.02.2007; published in revised form 01.03.2009

ABSTRACT

Purpose: In the following paper there have been the structure and properties of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 magnesium cast alloy as-cast state and after a heat treatment presented.

Design/methodology/approach: 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. The following results concern light and scanning microscopy, X-ray quantitative microanalysis and mechanical properties.

Findings: The examined alloys in as-cast state characterize a microstructure of α solid solution constituting the alloy matrix, the β – $Mg_{17}Al_{12}$ intermetallic phase in the form of plates located mostly at grain boundaries as well as near needle eutectic precipitations $Mg_{17}Al_{12}$ (α + β). In the structure one can also observe, using the EDS system, big concentrations of silicon, manganese and iron. The ageing process has caused the precipitation of evenly distributed dispersive β secondary phase in the needle form.

Practical implications: A good capability of damping vibrations and low inertia connected with a relatively low weight of elements have predominantly contributed to the employment of magnesium alloys for the fast moving elements and in locations where rapid velocity changes occur; some good examples may be car wheels, combustion engine pistons, high-speed machine tools, aircraft equipment elements, etc.

Originality/value: The undertaken examinations aim at defining the influence of a chemical composition and precipitation processes on the structure and casting magnesium alloy properties in its as-cast state and after heat treatment with a different content of alloy components.

Keywords: Heat Treatment; Metallography; Magnesium alloys; Structure

Reference to this paper should be given in the following way:

L.A. Dobrzański, T. Tański, L. Čížek, J. Madejski, The influence of the heat treatment on the microstructure and properties of Mg-Al-Zn based alloys, Archives of Materials Science and Engineering 36/1 (2009) 48-54.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

At the contemporary stage of the development of the engineering thought, and the product technology itself, material engineering has entered the period of new possibilities of designing and manufacturing of elements, introducing new methods of melting, casting, forming, and heat treatment of the casting materials, finding wider and wider applications in many industry branches. Engineers whose employment calls for significant expenditure of labour and costs strive to reduce material consumption. Therefore the development of engineering aims at designs optimizing, reducing dimensions, weight, and extending the life of devices as well as improving their reliability [1-6, 20].

The material selection is preceded by the analysis of many factors like: mechanical, design, environmental, urbanization, recycling, cost, availability, and weight related issues, which may change the existing conditions and emerge the needs resulting from the supplier-customer relation [1-9]. The strive to decrease the weight of products becomes an important challenge for designers and process engineers. The excessive weight verifies a significant extent the possibilities of employing particular material groups.

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. Magnesium alloys and their derivatives, alike materials from the lightweight and ultra-lightweight family, characterize of low density (1.5-1.8 g/cm^3) and high strength in relation to their weight [1-6]. Moreover, the magnesium alloys demonstrate good corrosion resistance, no aggressiveness towards the mould material and low heat of fusion, which make it possible to use pressure die casting that ensures good shape reproducibility.

Apart from the commonly used Mg binary alloys, ternary alloys (eg. Mg-Al-Zn, Mg-Al-Si) are very widely used, as well as their more complex ones (Fig. 1) [1-6].

The designers closer and closer cooperate with magnesium alloy manufacturers, which is a good example of the fact that currently about 70% of the magnesium alloy castings are made for the automotive industry. Lowering car weight by 100 kg makes it possible to save 0.5 l of petrol per 100 km. It is anticipated that in the following years the mass of castings from magnesium alloys in an average car will rise to 40 kg, internal combustion engines will be made mostly from the magnesium alloys and car weight will decrease from 1200 kg to 900 kg [5].

The concrete examples of the employment of castings from magnesium alloys in batch production in the automotive industry are elements of the suspension of the front and rear axes of cars, propeller shaft tunnel, pedals, dashboards, elements of seats, steering wheels, elements of timer-distributors, air filters, wheel bands, oil sumps, elements and housings of the gearbox, framing of doors and sunroofs, and others (Fig. 2) [1-6, 20].

A good capability of damping vibrations and low inertia connected with a relatively low weight of elements have predominantly contributed to the employment of magnesium alloys for the fast moving elements and in locations where rapid velocity changes occur; some good examples may be car wheels, combustion engine pistons, high-speed machine tools, aircraft equipment elements, etc. [1,6, 10, 15].

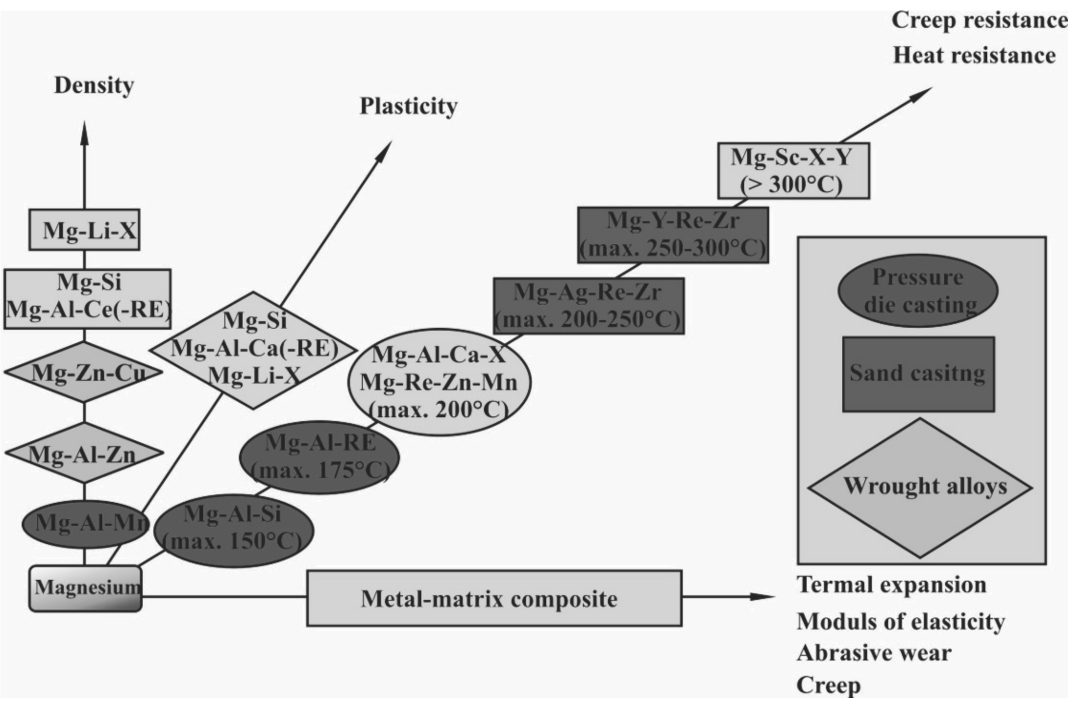

Fig. 1. Potential development directions of New magnesium alloys [5]

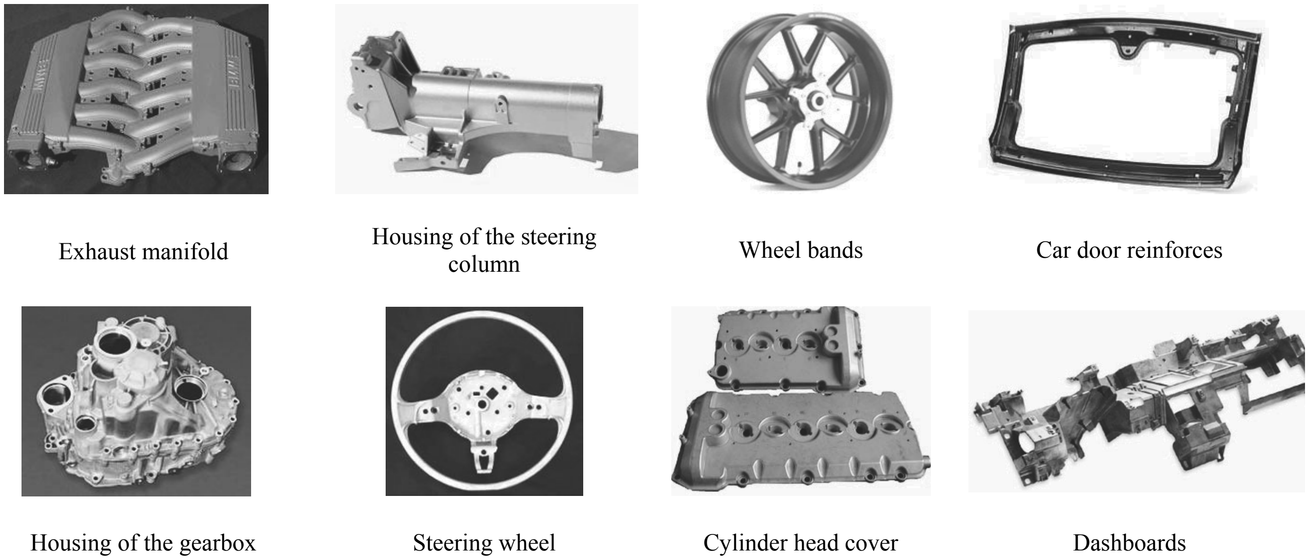

Fig. 2. Part of cars from magnesium alloys [1-6]

The wide application field for magnesium alloys is also developing in the textile industry. Replacing the cast iron moving elements and weaving loom seats with magnesium alloys technically and economically justified.

The employment of magnesium alloys for moving parts makes it possible to increase the frequency of their movements from 200 to 540 cycles per minute; therefore, the throughput of the weaving looms grows. Magnesium should find its application in the textile machine industry for many high-speed parts like: coils, fliers, spools, brush holders, and others [1-5].

Magnesium alloys have also found their application in manufacturing the mowers, saws, robots, office equipment including computer hardware, sport and medical appliances, in the production of movie and video cameras, space ships, and others.

A number of companies like BMW, Ford, General Motors, Chrysler, Alfa-Romeo, Sony, Toshiba, JVC, Sharp, Canon, Ericsson use magnesium alloy market is constantly growing. The products made from magnesium are still very expensive, yet customers get a high quality product, advanced both in technology and in functionality.

The increasing use of magnesium alloys is caused by the progress in the manufacturing of new reliable alloys with the addition of Zr, Ce, Cd and very light alloys are made from Li (used for constructions in the air-industry and for space vehicles) [2-4]. Because of the growing requirements for materials made from light alloys revealing mechanical properties, corrosion resistance, manufacturing costs and the influence on the environment, these efforts can be considered as very up-to-date from the scientific point of view and very attractive for further investigation.

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

2. Experimental procedure

The investigations were carried out on test pieces from the casting magnesium alloy made by ČKD Motory a.s. Hradec Králové in the as-cast state and after heat treatment (Table 1) with the chemical composition given in Table 2.

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
9.09	0.77	0.21	0.037	0.011	89.7905	0.0915
5.92	0.49	0.15	0.037	0.007	93.3347	0.0613
2.96	0.23	0.09	0.029	0.006	96.6489	0.0361

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	air	-	-	-
2	430	10	water	-	-	-
3	430	10	furnace	-	-	-
4	430	10	water	190	15	air

Castings in the form 200x100x15 mm plates were melted in a resistance furnace using a protective salt bad Flux 12 equipped with two ceramic filters by the applied melting temperature of 750±10°C (according to the manufactured alloy). Caused trough the metallurgical casting quality efforts of the manufactured alloy a refining with a neutral gas of the industry name Emgesalem Flux 12 was carried on. To improve the surface quality a protective layer Alkon M62 was applied. The caste material was heated in an electrical resistance furnace in protective argon atmosphere. The heat treatment involve the solution heat treatment and cooling in different cooling mediums as well water, air and furnace.

Fractures of the investigated materials were examined using the Philips Xl-30 scanning microscope. The X-ray quantitative analyses of the investigated alloy were carried out on the transverse microsections on the Philips scanning microscope with the EDX energy dispersive radiation spectrometer at the accelerating voltage of 20 kV.

The observations of the investigated materials structure were made on the transverse metallographic microsections using the light microscope.

Hardness tests were made using Zwick ZHR 4150 TK hardness tester in the HRF scale. Ten measurements were made for each test piece and the average value and standard deviation was calculated. Tensile strength tests were made using Zwick Z100 testing machine. Ten tests were made for each test piece and the average value and standard deviation was calculated.

3. Discussion of experimental results

Examinations of the chemical composition of the casting magnesium alloys using the EDX spectrometer confirmed the presence of the main alloying elements: magnesium, aluminium, manganese, and zinc. It was found out that the cast magnesium alloys were characteristic of the α solid solution microstructure featuring the alloy matrix and the β $Mg_{17}Al_{12}$ intermetallic phase was located mostly at grain boundaries. Moreover, in the vicinity of the β intermetallic phase precipitations the presence of the (α+β) eutectics was revealed (Figs. 3, 4). One can clearly observe in the structure of the casting magnesium alloys, not only the $Mg_{17}Al_{12}$ phase precipitations, the distinct aluminium, manganese and silicon concentrations, which indicate the presence of the MnAlFe and Mg_2Si type precipitations in the alloy structure (Fig. 4).

Phases containing Mg and Si are colored grey and have sharp edges in the shape of hexahedrons. Phases with high Mn concentration are irregular with a non plain surface, they often occur in the form of blocks or needles (Fig. 4).

After the air-cooling of the alloy the remainder amounts of the β ($Mg_{17}Al_{12}$) and MnAlFe phases were identified in the alloy structure in the α solid solution.

a) b) c)

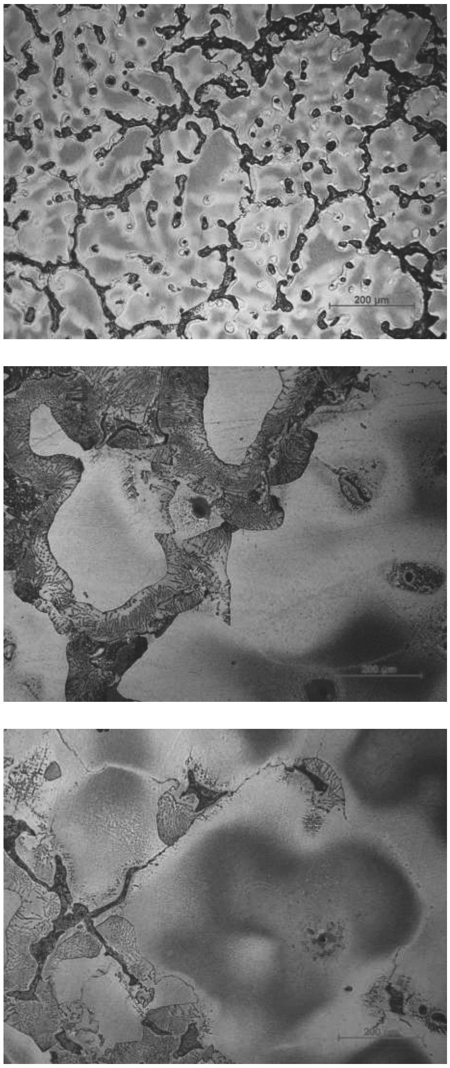

Fig. 3. Microstructure alloy MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 without heat treatment

After water cooling, the alloy precipitations in the α phase structure were revealed ($Mg_{17}Al_{12}$ and MnAlFe).

After cooling the alloy in the furnace the α structure was revealed and, moreover, locations of the α + β eutectic occurrences, several precipitations of the β ($Mg_{17}Al_{12}$) phases were located at the grain boundaries. Structure of this alloy is similar to the as-cast alloy structure.

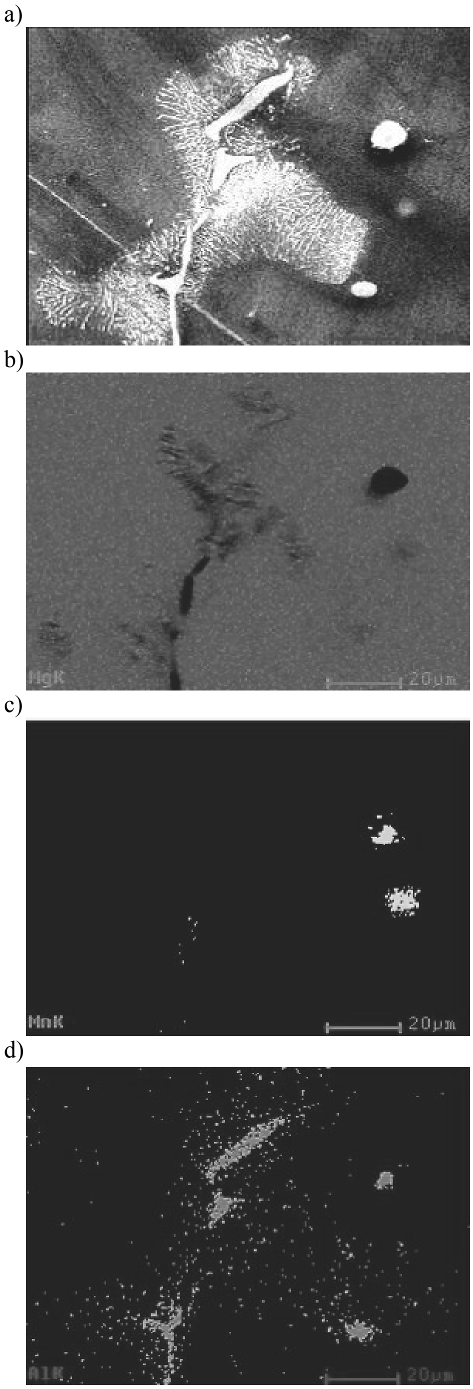

Fig. 4. The area analysis of chemical elements alloy MCMgAl9Zn1 after cooling in the air: image of secondary electrons a) and maps of elements' distribution b), c), d)

Observations of fractures after the static tensile strength test of the analyzed alloy made it possible to determine the effect of heat treatment on the nature of the investigated fractures (Fig. 5).

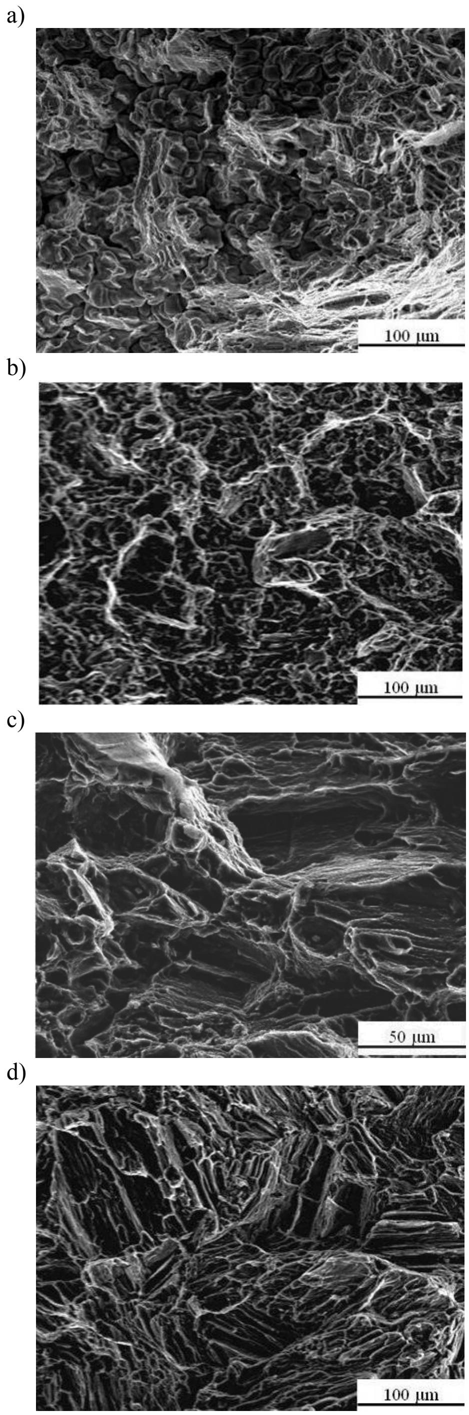

Fig. 5. The fracture surface of tensile test MCMgAl12Zn1 alloy: a) without heat treatment – as-cast, b) after cooling in the water, c) after cooling in the furnace, d) after aging treatment

The alloys after cooling in the furnace demonstrates a brittle fracture. The casting magnesium alloys after cooling in the water and air are characteristic of a ductile fracture (Fig. 5).

The results of the strain test allow to determine and compare the strength and plastic properties of the alloys without heat treatment and after heat treatment (Figs. 6-9). One of the conclusion the strength test is the fact that the heat treatment improves the mechanical properties of the alloy.

The heat treatment influences the growth of the strength properties, yield and hardness, by decreasing the elongation. A very high growth of the yield $Rp_{0.2}$ shows the alloys with 9 and 12% aluminum content after aging treatment.

Other falls the elongation increases almost four times for the case 1 and 2 compared to the as cast state.

The performed investigation, by the use of the Rockwell hardness tester, shows that the alloys have achieved the highest hardness after aging treatment. For the alloys mentioned above after cooling in the water and air hardness decreases slightly in comparison to the basic contents. For castings with 3% aluminum content, the highest hardness was achieved by the alloy after the solution heat treatment with cooling in water (Fig. 6).

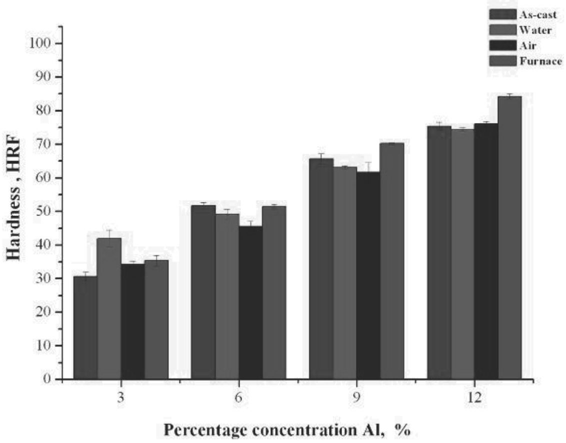

Fig. 6. The results of Hardness test

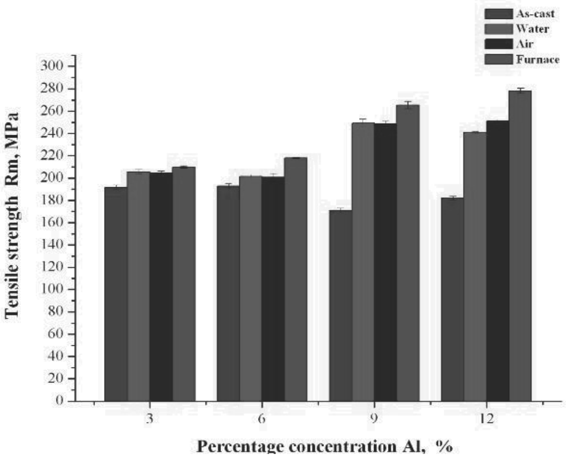

Fig. 7. The results of Tensile strength

4. Summary

The results of the EDX chemical composition analysis confirm the presence of magnesium, aluminum, manganese, and zinc, constituting the structure of α solid solution with the $Mg_{17}Al_{12}$ placed mainly on the grain order in the form of plates (Fig. 3).

Also the phase $MnAl_4$ with irregular shape, occurred often in the shape of blocks or needles (Fig. 4) and the Laves phase Mg_2Si. The phases containing Mg and Si coloured grey or light blue are characterized with sharp outlines with plain edges in form of particles.

The different heat treatment kinds employed contributed to the improvement of mechanical properties of the alloy and its yield point at the slight reduction of its plastic properties (Figs. 6-9).

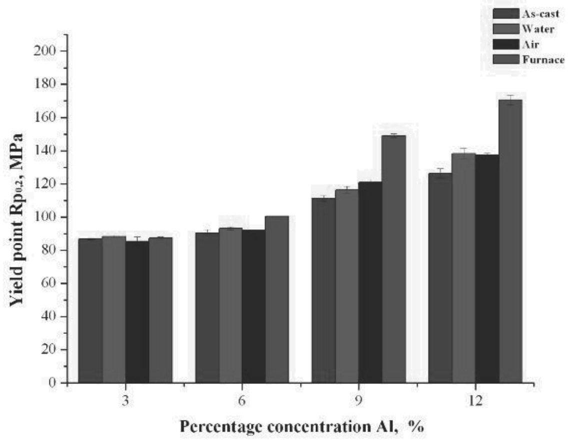

Fig. 8 The results of Yield point

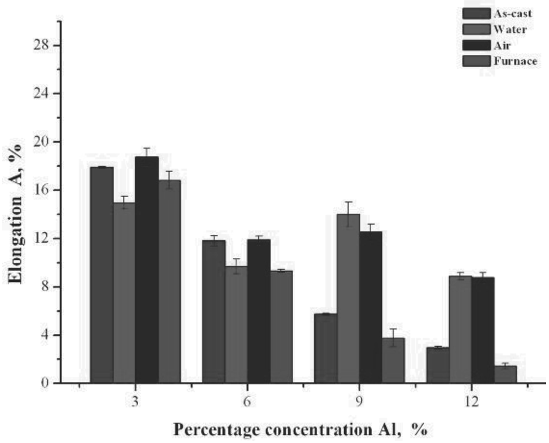

Fig. 9. The results of Elongation

Acknowledgements

This research work is financed in part within the framework of science financial resources in the period 2007-2008 as a research and development project R15 0702 headed by Prof. L.A. Dobrzański.

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