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Mechanical properties and wear resistance of magnesium casting alloys

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ABSTRACT

Purpose: In the following paper there have been the properties of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1magnesium 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±10°C, suitable for the manufactured material. The following results concern abrasive wear, mechanical properties, light and scanning microscopy.
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 mechanical properties and 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; Mechanical properties; Fracture mechanics; Magnesium alloys

1. Introduction

A contemporary technological development makes it necessary to look for new constructional solutions that aim at the improvement of the effectiveness and quality of a product, at the minimization of dimension and mass as well as the increasing of reliability and dimension stability in the operation conditions. For a dozen or so years one can observe a rising interest in the non-ferrous metals alloys including magnesium alloys. The dynamic industrial development puts some higher and higher demands to the present elements and constructions. These demands belong production and research newer and newer materials for materials

Table 1.
The examples of applications magnesium alloys at present and in the future [8, 16, 17]

Power transmission system	Interior equipment	Chassis	Motor-car body
Gearbox	Steering gear	Wheel bands	Luggage boot construction
Ramified exhaust manifold	Steering rod bracket	Suspension arms (rear and front)	Inner door cast elements
Crankcase	Dashboard	Rear bracket	Sheet elements
Cylinder head cover	Clutch and brake pedals	Engine platform	Extrusion elements
Oil pump casing	Air cushion elements	Steering shaft	Interior and exterior reinforcements
Oil sump	Seat components	–	Articulated joints
Transfer box	Lock casing	–	Head-lights
Valve housing	Armrest casing	–	Hood
–	Deck computer and radio casings	–	Bumper
–	Air cushion frame	–	–


Cooling system pump casing
Wheel bands
Casing of the computer
Casing of the minidisk

Fig. 1. Elements from magnesium alloys [1, 8]

engineering materials with relation to predictable work conditions and arise needs [1-5, 9, 12, 17-19, 21]. Magnesium alloys gets a huge importance with present demands for light and reliable construction.

Magnesium alloys have low density and other benefits such as: a good vibration damping and the best from among all construction materials: high dimension stability, small casting shrinkage, connection of low density and huge strength with reference to small mass, possibility to have application in machines and with ease to put recycling process, which makes possibility to logging derivative alloys a very similar quality to original material [1, 8, 24].

A desire to create as light vehicle constructions as possible and connected with it low fuel consumption have made it possible to make use of magnesium alloys as a constructional material in car wheels, engine pistons, gear box and clutch housings, skeletons of sunroofs, framing of doors, pedals, suction channels, manifolds, housings of propeller shafts, differential gears, brackets, radiators and others (Table 1). A number of companies as well as the use of magnesium and its alloys are still growing. Products made of magnesium and its alloys are still relatively expensive, however customers get high quality products, advanced both in technology and functionality. Generally they are applied in motor industry and machine building, but they find application in a helicopter production, planes, disc scanners, a mobile telephony, computers, bicycle elements, household and office equipment, radio engineering and an air - navigation, in chemical, power, textile and nuclear industrial (Fig.1) [6, 7, 10, 11, 13-16, 25].

The rising tendencies of magnesium alloy production, show increased need of their application in world industry and what follows the magnesium alloys become one of the most often apply

Table 2.
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 3.
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

construction material our century. The goal of this paper is presentation of the investigation results of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 casting magnesium alloy in its as-cast state and after heat treatment.

2. Experimental procedure

The investigations were performed on experimental magnesium alloys MCMgA112Zn1, MCMgAl9z1, MCMgAl6Zn1, MCMgAl3Zn1 in stable state and after heat treatment (Table 3). Chemical composition of this materials was conditioned by changeable concentration range of aluminium in accordance with different types of alloy, which changes in range from 3-12% (Table 2).

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.

The observations of the investigated cast materials have been made on the electron scanning microscope Opton DSM-940.

Hardness tests were made using Zwick ZHR 4150 TK hardness tester in the HRF scale.

Tensile strength tests were made using Zwick Z100 testing machine.

The wear resistance test of cast magnesium alloys in meat-metal system was carried out with a help of tool, which was designed in Institute of Engineering Materials and Biomaterials, Silesian University of Technology (Fig. 2). The process of samples preparation depends on surface polishing on sandpaper with granulation of 1200 and on mechanical grinder supplied by STRUERS company. The main aim of this process is to get four flat and equal surfaces. As a initial result of investigation was established a minimum clamp and cycle numbers. The investigation were performed with a stable cycle numbers 5000 (120 m), with different loads 6, 8, 10 12 N. Samples were cleaned in ultrasonic washer before and after a test, because they should be cleaned, next they were weighed in order research a loss mass on analytic water with precision 0,0001 g.

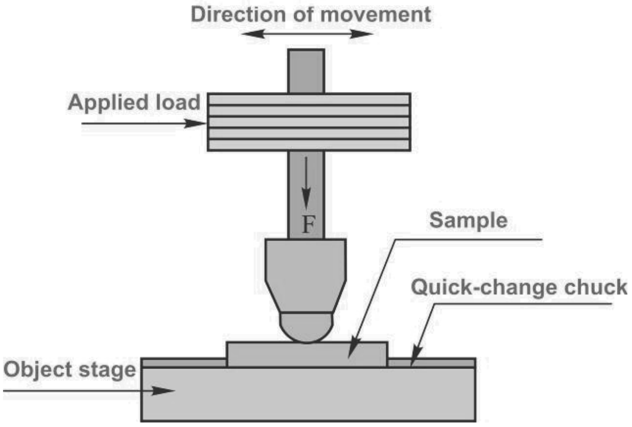

Fig. 2. Pictorial diagram to the abrasive wear investigations in a metal-metal system

The results in the work, were statistical worked out, for each measurement of the average value, standard deviation.

3. Discussion of experimental results

The results of the static tension test make it possible to determine and compare the mechanical and plastic properties of the examined magnesium cast alloys in as cast and after heat-treatment (Fig. 3). On the basis of the tests done, one has stated that the biggest resistance to tension in as cast state show the MCMgAl6Zn1 and MCMgAl3Zn1 alloys which also posses the biggest state elongation. It has also been proved that the increase of the Al concentration from 6 to 12% reduces the resistance to tension in as cast state. The heat-treatment i.e. the solution heat treatment with the furnace cooling and ageing, causes the increase of the resistance to tension. The maximum resistance to tension has been obtained after the ageing of the MCMgAl12Zn1 alloy; one has also observed a significant (by 50%) increase of the resistance to tension for the MCMgAl9Zn1 specimens after ageing. The smallest growth of the resistance to tension after the heat-treatment has been gained for the MCMgAl6Zn1 and MCMgAl3Zn1 materials, 30.3 and 12.4 MPa respectively. The differences in values of the resistance to tension for the alloys subjected to solutioning with water and air cooling amount to 6 MPa maximum.

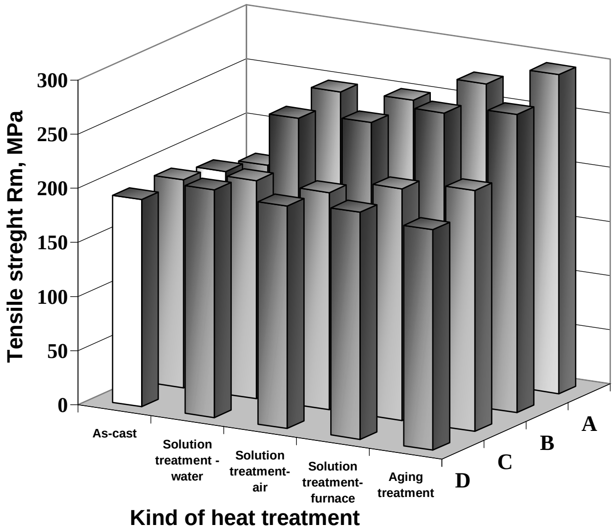

Fig. 3. The results of Tensile strength magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1

Specimens with 12% concentration of aluminum–MCMgAl12Zn1 show a maximum yield point in as cast state (Fig. 4).

The biggest value of the yield point after the heat treatment show the MCMgAl12Zn1, MCMgAl9Zn1 and MCMgAl6Zn1 alloys after the solutioning with furnace cooling, insignificantly higher than in the case of the aged materials. The increase of the aluminum concentration to 12% diminishes the elongation of the examined alloys to the value of 2.97%±0,07, five times lower in comparison to the elongation of the MCMgAl3Zn cast alloys. The solution heat treatment with water and air cooling causes the increase of the value of elongation even by 100% for MCMgAl12Zn1 and MCMgAl9Zn1 alloys. The alloys after the solution heat treatment with furnace cooling and ageing are characterized by an insignificant fall of the elongation in relation to the as cast state (Fig. 5).

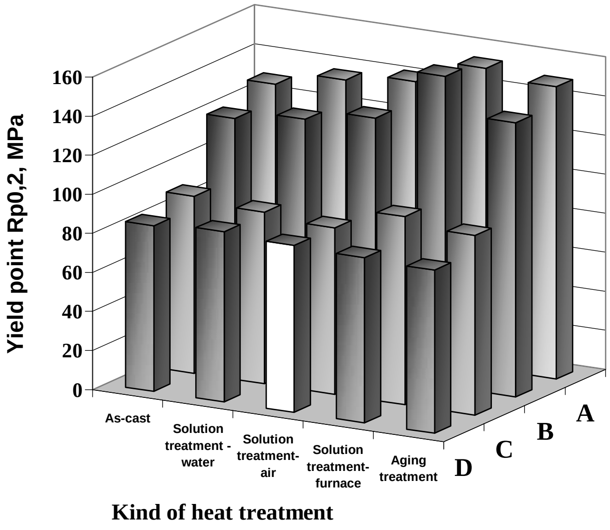

Fig. 4. The results of Yield point magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1

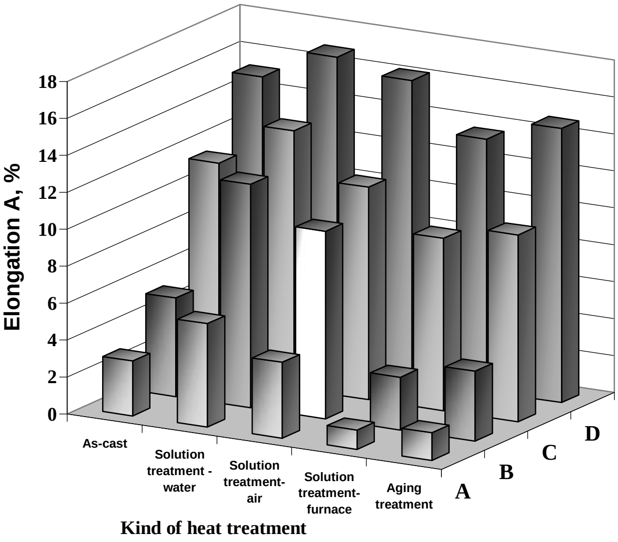

Fig. 5. The results of Elongation magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1

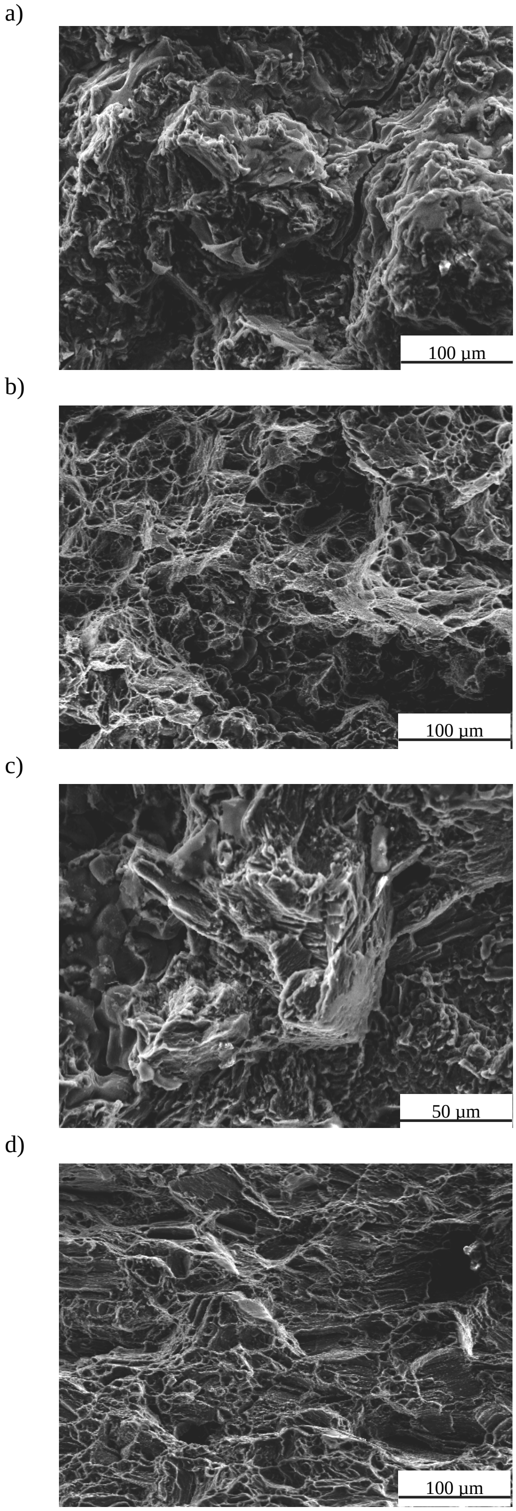

Fig. 6. The fracture surface of tensile test alloy MCMgAl9Zn1: a) without heat treatment – as-cast, b) after cooling in the air, c) after cooling in the furnace d) after aging treatment

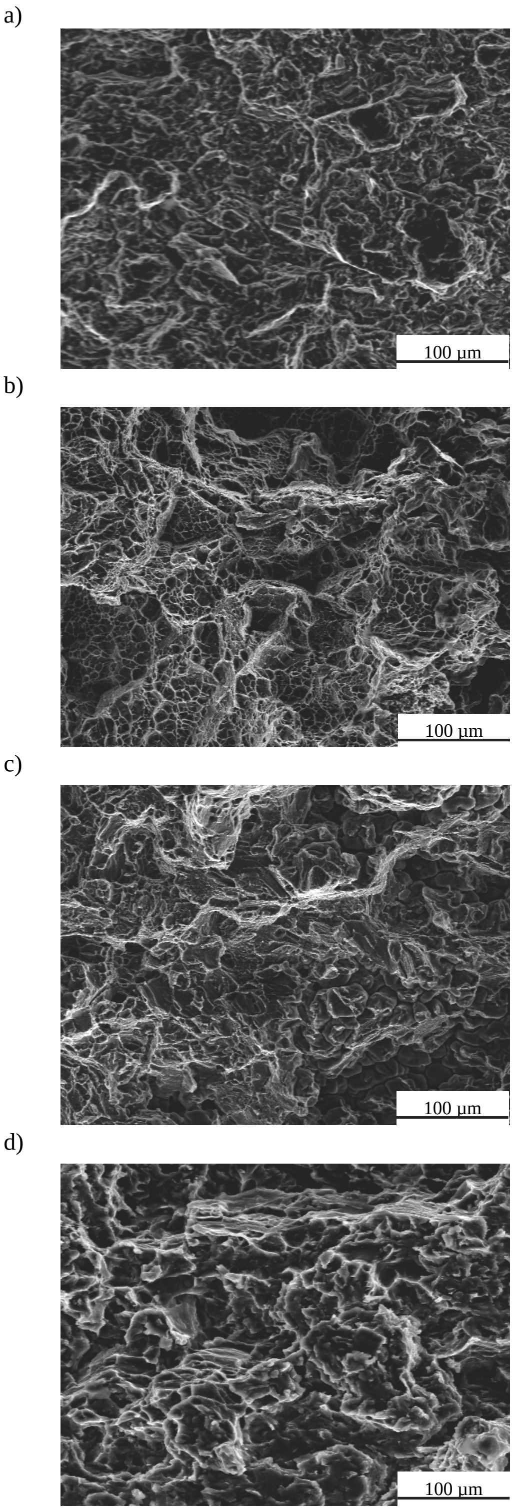

Fig. 7. The fracture surface of tensile test alloy MCMgAl6Zn1: a) without heat treatment – as-cast, b) after cooling in the air, c) after cooling in the furnace d) after aging treatment

For fuller characteristics of the influence of the heat treatment and the aluminum concentration on the properties of the magnesium cast alloys, the pictures of the structures of factures after a static test of elongation, have been presented in Figures 6 and 7. One of the results of the carried out investigations is the fact that MCMgAl12Zn1, MCMgAl9Zn1 and MCMgAl6Zn1 alloys in as cast state are characterized by a mixed fracture, whereas in the case of the MCMgAl3Zn alloys one can observe a ductile fracture (Figs. 6, 7). Subjecting the alloys to the heat treatment consisting in solutioning with water and air cooling, has increased the plasticity of the alloys, which may prove the ductile, in most cases, character of the fracture, and the increase of the contraction and elongation values. The MCMgAl12Zn1 and MCMgAl9Zn1 alloys, in turn, heated and cooled with furnace as well as subjected to ageing, in which a significant increase of hardness in comparison with the initial state and an insignificant lowering of the contraction and elongation values took place, show a brittle fracture character; in the MCMgAl6Zn1 and MCMgAl3Zn alloys the mixed fracture has been observed.

To compare the resistance to wear in conditions simulating the working conditions of the cast magnesium alloys, the abrasive wear investigations have been made in a metal-metal system (Fig. 8, 9). The results of the grindability test done show that the smallest average mass loss in as cast and after the heat treatment at the increasing load from 6 to 12 N is for the MCMgAl12Zn1 alloys. These alloys are characterized by the best tribological properties among the examined materials. Whereas the biggest mass loss for the analyzed cases in the initial state and after the heat treatment has been proved for the MCMgAl3Zn alloy. The biggest as well as the smallest resistance to wear of the examined magnesium alloys, revealed by the average mass loss, corresponds to the results of the hardness of these materials.

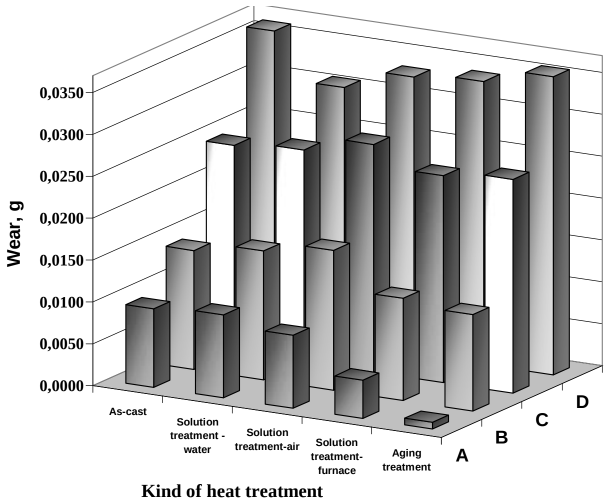

Fig. 8. The results of wear resistance test magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1, with loads 6 N

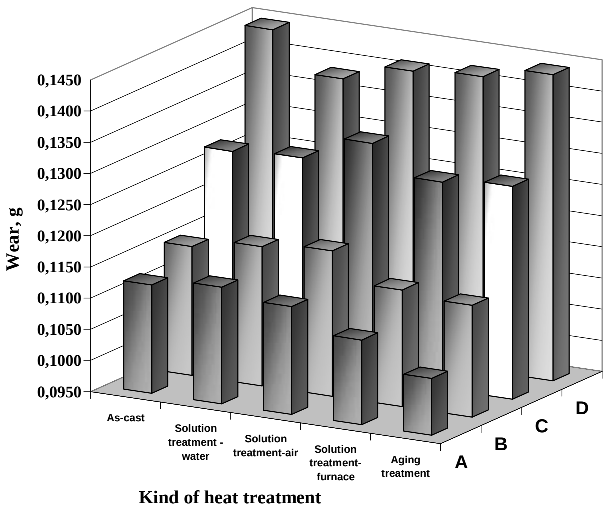

Fig. 9. The results of wear resistance test magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1, with loads 12 N

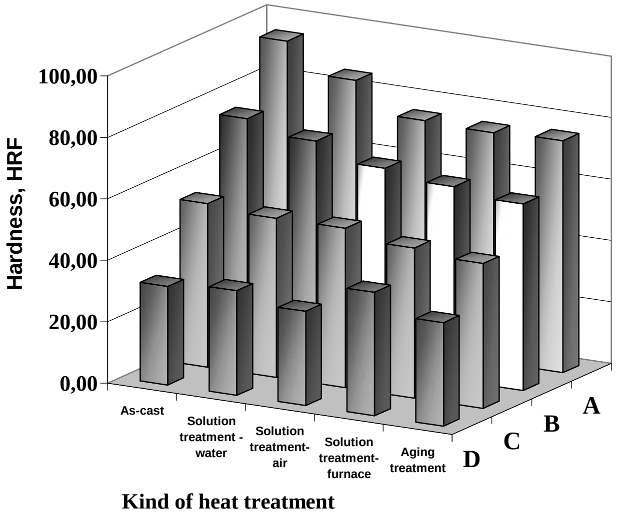

Fig. 10. The results of Hardness magnesium casting alloys: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1

Together with the growth of the concentration of aluminum from 3 to 12% in the analyzed alloys, grows their hardness (Fig. 10). The biggest hardness 75.4±1.15 HRF in as cast state show the casts from the MCMgAl12Zn1 alloy. It is over two times higher than for the MCMgAl3Zn alloy. Subjecting the material to the heat treatment (solutioning and ageing) has caused the increase of its hardness. The MCMgAl12Zn1, MCMgAl9Zn1 and MCMgAl6Zn1 alloys have reached their highest hardness after the ageing. For the cases after the solution heat treatment, the hardness insignificantly decreases in comparison to the initial state. For the MCMgAl3Zn casts, the biggest hardness show specimens after the solutioning with water cooling, and for the remaining cases the hardness results are similar.

4. Summary

Precipitation hardening causes some changes in the resistance properties (Figs. 3, 4). The biggest resistance to elongation in as cast state show the MCMgAl6Zn1 and MCMgAl3Zn alloys, 192.1±1.95 and 191.3±1.6 MPa respectively. They also have the biggest elongation in as cast state (Fig. 5). It has also been proved that the increase of the Al concentration from 6 to 12% lowers the resistance to elongation in as cast state to 170.9±1.64 MPa. The maximum plasticity border has been obtained for the MCMgAl12Zn1 alloy, insignificantly higher than in the case of the MCMgAl9Zn1alloy. In as cast state the smallest elongation show materials with 12% aluminum concentration MCMgAl12Zn1, over five times smaller in comparison with the elongation values of the MCMgAl3Zn cast alloys. After the ageing with air cooling, the maximum increase of the resistance to elongation 124±1.7 MPa and the plasticity border 20±0.1 MPa has been gained for the MCMgAl12Zn1 alloy. The alloys after the ageing show the insignificant decrease of the elongation in relation to the as cast state. The obtained results show that the carried out heat treatment of the investigated materials causes the increase of their resistance to abrasive wear (Figs. 9, 10).

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