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New magnesium alloy with promote properties for automobile construction

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Abstract
The effect of scandium on structure and phase composition of the heat-resistant magnesium alloy ML10. Shown its positive effect (0.07%) on the mechanical properties and long-term strength at elevated temperatures castings of magnesium alloys for the automotive industry.

Keywords: *magnesium alloy, structure, mechanical properties, heat-resistance, intermetallic phase.*

Introduction

Automobile transport weight-saving is the priority task for producers as it allows to increase their coefficient of efficiency, reduce fuel consumption and increase reliability and endurance of service [1]. But in spite of all the efforts the structural weight of autos tended to increase because of the addition of numerous auxiliary devices and mechanisms, improving convenience and safety of traffic. Solution of this problem is possible by means of light materials, magnesium alloys in particular, developing.

Magnesium alloys have a lot of advantages compared with other alloys on the basis of non-ferrous metals: low-density, high strength-to-density ratio and ratio of elastic, the ability to absorb hit energy and vibrational motion energy. That is why they are suitable for automobile industry. Nowadays the forces of world automobile industry are focused on the enhancement of magnesium alloys casting usage [2].

For manufacturing of combustion engines and transmission systems magnesium alloy ML10 is used (% mass: 0,1…0,7 Zn, 2,2…2,8 Nd, 0,1…1,0 Zr, the other - Mg). Its basic elements, forming heat-resistant intermetallic phases, provide good efficiency characteristics of alloy at high temperature [3]. However, technical requirements submitted to modern systems and mechanisms, stiffen the conditions of their operation and require steady increase of their characteristics. The most reasonable decision of the given task is improvement of materials used by means of controlling their structure and properties [4,5,6].

The scandium is known to affect positively on mechanical and heat-resistant properties of aluminum- containing alloys by forming complex heat-resistant intermetallides [7]. That is why the influence of scandium on structure and properties of heat-resistant alloy ML10, having in its composition heat-resistant intermetallides phases $(MgZr)_{12}Nd$, that will allow to increase reliability and endurance of produced parts and broaden the area of its application, is of great interest.

The influence of scandium on mechanical properties and heat-resistance of magnesium alloy ML10 was studied.

The magnesium alloy ML10 was smelted in series in induction crucible furnace IPM- 500. Alloy finishing was executed in holding furnace with partial extraction. Into alloy some increasing ligature agents were added (10 % Sc, 90 % Mg) and standard samples for mechanical test were poured into sandshale casting box.

These samples were subjected to heat treatment in Belvju furnaces and PAP-4M furnaces under following modes: quenching from $415^{\pm5}$ °C, soaking during 15 hours, cooling in the air and age-hardening at $200^{\pm5}$ °C, soaking during 8 hours, cooling in the air.

Rupture strength (σ_r) and elongation ratio (δ) of samples with 12 mm functional diameter were determined with the help of R5 pull test machine under normal temperature.

Creep rupture strength (σ) was determined at different temperatures with the help of AIMA 5-2 pull test machine on the samples with 5 mm functional diameter.

Microtexture of castings was examined with the help of microscope "Neophot 32" after etching operation by agent containing 1% of nitric acid, 20% of acetic acid, 19% of distilled water and 60% of ethylene alcohol.

Microhardness of alloy microconstituents was determined with the help of "Buehler" microhardness tester under load 0.1N.

Electron probe microanalysis of microconstituents was executed on the "JSM-6360LA" electron microscope.

The macrofractographic analysis of sample fractures of examined metal showed that with increasing of scandium content the macrograin broke, the nature of fracture was dull and finely crystalline (fig.1). However, if the scandium content more than 0.7% there appeared defects in fractures of metal that are typical for rough microporosity and film impurities (fig2).


a


b


c

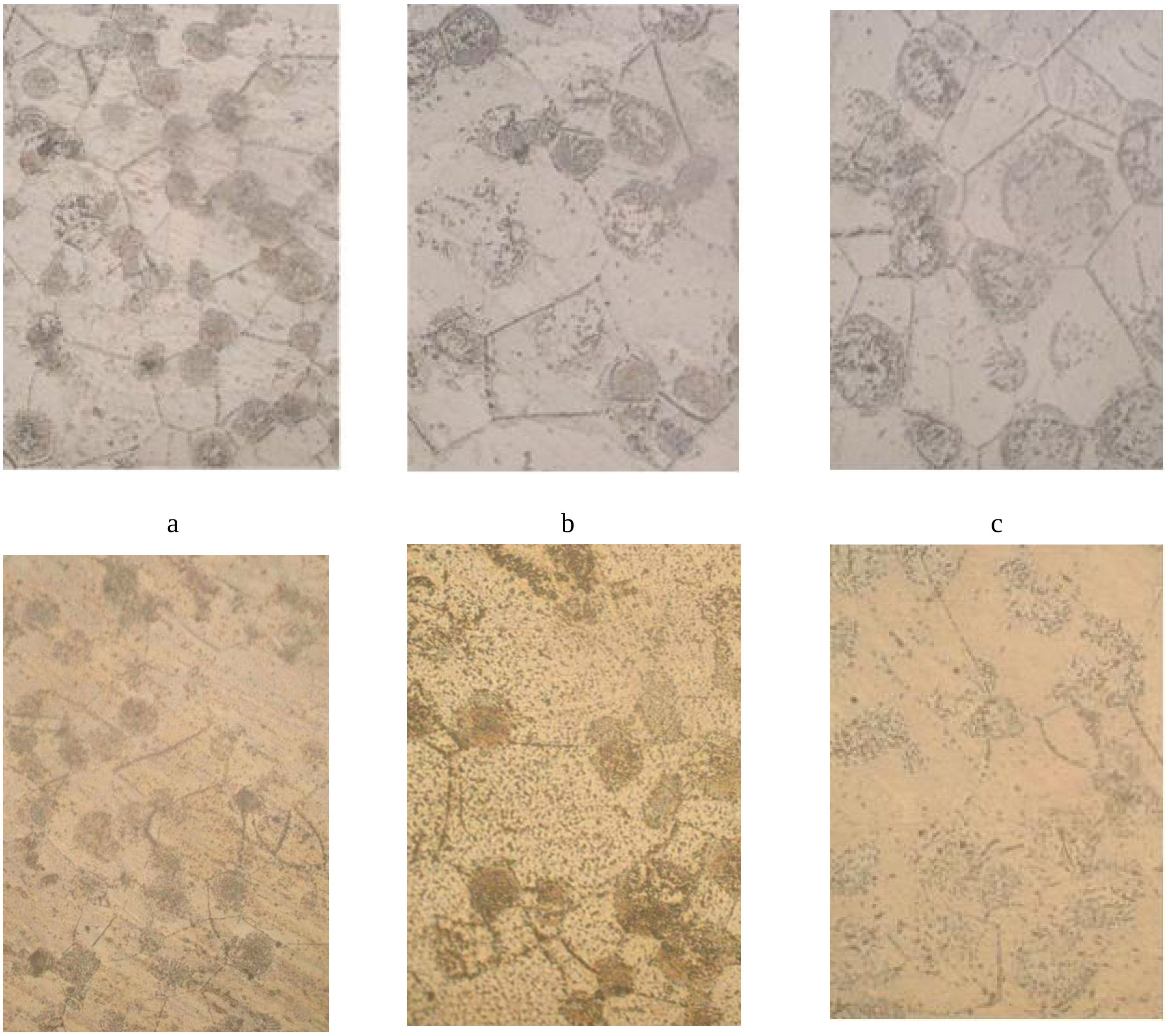

d

Figure 1 Macrostructure of ML10 alloy with different scandium content: a - without Sc, b - 0,05 % Sc, c - 0,1 % Sc, d - 0,3 % Sc (x 3).

Figure 2 Coarse scabs in samples of ML10 alloy with additive 1.0 % Sc, x100.

Microstructure of heat-treated ML10 alloy, casted according to standard process, is presented as δ-solid solution with eutectoid δ+$(MgZr)_{12}Nd$ in form of spherical shape areas. With increasing of scandium content there was increasing of the size of spherical areas of eutectoid escape in the alloy (fig. 3 a, c). While introduction into the alloy over 0.07% of Sc, the size of eutectoid spherical areas increase in four times compared with standard alloy, while the size of δ –phase was more or less stable (fig. 4).

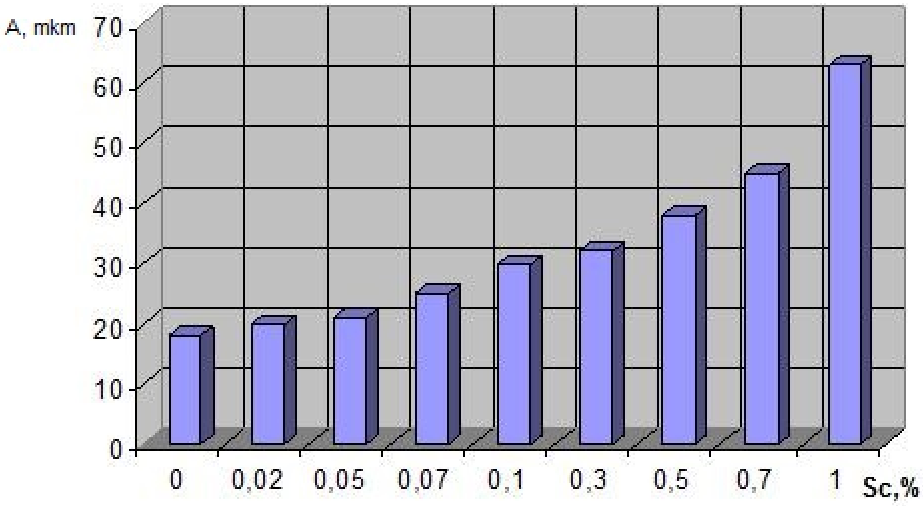
b



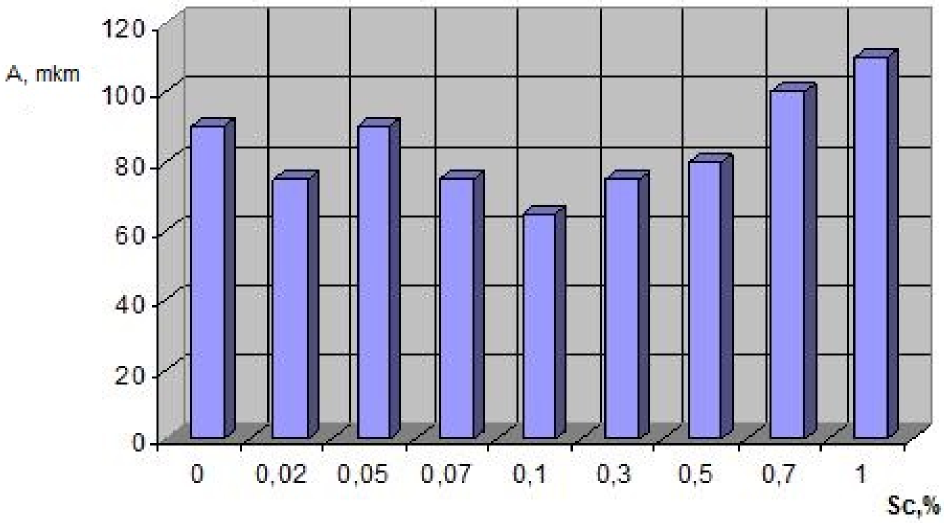
a b c

d e f

Figure 3 Microstructure of ML10 alloy without addition of Sc (a, d) with addition 0.05% Sc. (a, d) and 1.0% Sc (c, f) x: 500 a, b, c - after standard heat-treatment, d, e, f - after examination at 150 C (1252 h) +250 C (strain 80 MPa).



a

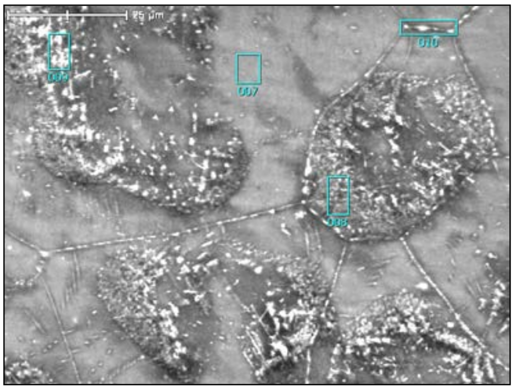


b

Figure 4 Sizes of microconstituents (A) of heat-treated ML10 alloy with different scandium content: a - $\delta+(MgZr)_{12}Nd$ – phase, b - δ – phase.

Heat treatment contributed to increasing of alloy homogeneity as result of elements reassignment between axes and interaxes of dendrite spaces, and complemental alloying of a die by means of the elements diffusion from interfacial phase separation $(MgZr)_{12}Nd$.

Electron probe microanalysis provided by electron microscope "JSM-6360LA" showed, that spherical areas are treated mostly by zirconium, neodymium and scandium (fig. 5). In modified alloys the scandium content in spherical areas of eutectoid separation $\delta+(MgZr)_{12}Nd$ in ~ 1.5…2.0 times higher, than in δ-solid solution.



No of the area	Content of elements, % *						Total, %
	Mg	Al	Si	Sc	Zr	Nd	
007	97,59	-	0,1	0,19	0,1	2,02	100
008	93,07	0,45	0,08	0,57	1,83	4	100
009	92,36	-	0,17	0,54	4,03	2,9	100
010	96,1	-	0,17	0,24	0,53	2,96	100

Figure 5 Electron probe microanalysis of microconstituents of ML10 alloy with addition 0.5 % of Sc.

* - the data is of evaluative character

There was grain refinement while increasing scandium concentration in the alloy to 0.3%. Further increasing of scandium addition (to 1.0%) leads to enlargement of micrograin size to 160 micron (at 0.02…0.3 % Sc the micrograin size is ~ 75 micron).

In heated to 150…250°C samples there was resolution of eutectoid (fig. 3 d-f). Microstructure analysis showed, that while thermal effect and prolonged keeping together with resolution of eutectoid there took place its solution in the die with further separation of complex intermetallide phase of $(MgZr)_{12}Nd$ type with scandium in form of fine particles (fig. 6). Whereby fine intermetallide particles separated inhomogeneously, forming the areas of dark streak pattern, that is characterized by increasing of microhardness.

Figure 6 Inhomogeneous separation of secondary intermetallide phase in the sample of ML10 alloy after prolonged keeping (1252 hours, σ_r = 80MPa) at the temperature 150°C, x750.

It was established that, to more complete resolution of eutectoid phase serves the time of keeping at the given temperature and strain. At temperature 270°C there observed roughening of the structure as a result of intensive separation of intermetallides, especially at the grain boundaries. It explains the sharp drop of refractory qualities of the material. Coarse interfacial separations were found in the structure of samples, containing over 0.07% Sc, which led to the rapid damage of samples while creep-rupture test.

Microhardness of δ-solid solution of standard alloy (before heat treatment) is more than 3 times lower than microhardness of separations in spherical eutectoid areas. After heat treatment there was increasing of a die microhardness and reduction of eutectoid hardness value. It indicates the increasing of heat-treated alloy homogeneity (table 1).

Table 1 Microhardness of microconstituents in samples of ML10 alloy after creep-rupture test.

Amount of Sc, % mass	Microhardness after creep-rupture test. (σ_r80 MPa) HV, MPa					
	die			eutectoid		
	T_t50°C	T_t50°C	T_t70°C	T_t150°C	T_t250°C	T_t270°C
-	824.0… 894.1	824.0… 1064.0	894.1… 1354.4	1026.6… 1114.1	1225.5… 1504.7	1589.5… 2011.7
0.02	894.1… 1064.0	894.1… 1017.3	681.0… 824.0	1114.1… 1167.8	1167.8… 1225.5	733.4… 857.3
0.05	894.1… 1017.3	894.1… 1017.3	733.4… 857.3	1114.1… 1167.8	1167.8… 1225.5	824.0… 949.5
0.07	894.1… 973.5	1064.0… 1114.1	894.1… 914.1	1114.1… 1167.8	1167.8… 1225.5	973.5… 1167.8
0.10	894.1… 973.5	1064.0… 1114.1	894.1… 914,1	1114.1… 1167.8	1167.8… 1225.5	973.5… 1167.8
0.30	894.1… 973.5	1064.0… 1114.1	894.1… 914.1	1114.1… 1167.8	1167.8… 1225.5	973.5… 1167.8
0.50	894.1… 973.5	894.1… 1064.0	933.4… 973.5	1114.1… 1167.8	1167.8… 1354.4	1167.8… 1225.5
0.70	824.0… 894.1	994.1… 1164.8	923.1… 932.5	1064.0… 1167.5	1225.5… 1354.4	1167.8… 1649.5
1.00	967.8… 1114.5	1044.1… 1184.3	923.1… 932.5	1167.8… 1354.4	1225.5… 1504.7	1167.8… 1649.5

It is shown that, increasing of scandium concentration in ML10 alloy leads to the increasing of microhardness values of microconstituents before and after heat treatment. With increasing of keeping time at temperatures 150…250 °C there was reduction of microhardness of the examined alloys by means of more complete resolution of eutectoid of δ+$(MgZr)_{12}Nd$ type.

The addition of scandium to the ML10 alloy to 0.07% contributed to the improving of the mechanical and heat-resistant properties (table 2).

Further increasing of scandium content in alloy leads to some reduce of mechanical characteristics of the material.

Increasing of the creep rupture strength test temperature to 270C has reduced the time to fracture in ~ 6 times. Samples with addition 1.0% Sc have damaged when subjected to loadings at temperature 250 °C because of formation of the porosity and film impurities.

Table 2 Mechanical properties and creep rupture strength* of ML10 alloy

Amount of scandium, % mass	Mechanical properties		Creep rupture strength, σ_r=80 MPa, hour.		
	σ_r, MPa	δ, %	$T^{**}_{t.}$=150/250°C;	T_t=250°C;	$T_{t.}$=270°C;
-	235.0	3.6	$1251^{30}/26^{15}$	47^{30}	9^{00}
0.02	253.0	4.6	$1252^{00}/56^{00}$	53^{10}	11^{10}
0.05	245.0	6.3	$1252^{00}/48^{45}$	71^{30}	16^{00}
0.07	240.0	4.0	$1252^{30}/64^{00}$	61^{40}	12^{20}
0.10	232.0	3.5	$1252^{30}/48^{00}$	36^{30}	13^{20}
0.50	235.0	4.0	$1251^{30}/34^{10}$	24^{00}	6^{45}

1.00	169.0	3.3	$1252^{30}/8^{00}$	-	-

Note: * average values;** testing of the samples for creep rupture strength was executed on a staggered basis: at 150°C (numerator), then at 250 °C (denominator).

Conclusions

Modification of ML10 alloy with scandium in the amount of 0.05…0.07 % improves the micro- and macrostructure of the metal that contributes to improving of mechanical properties and refractory qualities of magnesium casting.

The usage of magnesium alloy castings of ML10 type, modified by scandium for automobile manufacturing will allow reduce their weight, improving the reliability and endurance of operation.

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