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Effect of selected microadditives on the mechanical properties of aluminium alloys

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Abstract

The effect of iron impurities on microstructure and mechanical properties of cast Al-Cu and Al-Zn-Mg alloys was discussed. The role of iron in the process of solutioning and ageing of these alloys was described. Basing on the results of investigations, a comparative analysis was made to disclose the effect of low content (microadditives) of the elements, like Mn, Ti, Zr, B, Cr, Ni, Zn, Sn, Cd, In, Mg, Sb, and Ag on the primary structure of castings, mainly on the morphology of iron-bonding intermetallic phases. The studies also allowed for an effect of these elements on dispersion hardening of the examined alloys, reflected in an improvement of the principal mechanical properties (R_m, A_5, HV), and on the kinetics of ageing. Tin, cadmium and indium, added in an amount of 0,1 – 0,15 %, were reported to have the strongest effect on the process of dispersion hardening. Beneficial effect on the morphology of iron phases have manganese, chromium and nickel.

Keywords:
Cast aluminium alloy; Aluminium-copper alloys; Aluminium-zinc-magnesium alloys; Dispersion hardening; Mechanical properties

1. Introduction

Aluminium alloys in as-cast condition are characterised by relatively low mechanical properties. Yet, through proper choice of the chemical composition, of metallurgical and foundry conditions under which castings are made, and of the dispersion hardening parameters, exceptionally high mechanical properties can be obtained in castings made from these alloys. Technical literature describes aluminium alloys with combinations of various additives, selected to improve the properties of castings [1-3,5,7,8]. On the other hand, even if optimum parameters of the heat treatment are observed, maximum properties may not be sometimes obtained in these alloys. The reason are, among others, some impurities casually occurring in these alloys, specially iron admixtures [1,2,4]. Remembering this fact, the studies were undertaken to establish what effect various contents of iron (0,05-1,5%) may have on structure, properties and parameters of the heat treatment of Al-Cu alloys containing 4 - 6% Cu, and on the parameters of Al-Zn-Mg-Cu alloys containing about 5% Zn, 3%Mg and 0,8%Cu. The above given chemical composition of Al-Zn-Mg-Cu alloy, as regards the content of the main alloy constituents, ensures after dispersion hardening optimum mechanical properties of this material [8]. The second stage of the studies included investigations of an effect of the low content of various microelements (Mn, Ti, Zr, B, Cr, Ni, Zn, Sn, Cd, In, Mg ,Sb, Ag) on microstructure and properties of the above mentioned aluminium alloys, considered as a means of compensating the adverse effect of high iron levels. Microadditives are introduced mainly to enhance the effect of solid solution hardening during ageing. Some of these elements exert a very strong effect on the primary structure, changing the configuration of intermetallic phases or refining the structure.

2. Methods of investigation

Alloys were melted in electric furnace with chamotte-graphite crucible. The charge was composed of the following materials: Al99,999; AlCu50 and AlFe30 master alloys; Mg1 magnesium and EO1 zinc. Alloys were cast into metal moulds preheated to a temperature of about 523K and to dry sand moulds. Specimens for mechanical tests of the measuring diameter ∅ 10 mm and bars of ∅ 25x250 mm were cast. Average cooling rate of the specimens for mechanical tests carried out within the temperature range of 873K-723K was 6-8 K/s (for metal mould) and 0.8-0,9 K/s (for sand mould).

Test castings were solution-treated and aged. At the first stage of treatment (solutioning), the specimens of Al-Cu alloy were isothermally preheated at a temperature of 788K for 8-48 hours. In the case of AlZnMg alloy, the solutioning was carried out at a temperature of 763 K. Ageing was carried out at 393K and 433K for a time varying from 0,5h to 250h.

The specimens in as-cast state and after heat treatment were used for metallographic examinations, for static tensile test (the tensile strength R_m and elongation A_5 were determined) and Vickers hardness measurements (HV 30).

3. Discussion of results

3.1. Effect of iron presence on the microstructure and properties of dispersion hardened alloys

Tests have proved that Al-Cu alloys of the lowest iron content (0,02-0,05%Fe) have in as-cast condition the structure composed of the dendrites of α(Al) solution and binary α(Al)+ Al_2Cu eutectic. In the structure of alloys containing higher levels of iron appear the intermetallic phases of iron mixed with aluminium and copper. The presence of two types of these phases was reported. They differ in the content of iron and in the shape of the precipitates; these are the following phases: Al_7Cu_2Fe phase of acicular shape and $Al_6(Cu,Fe)$ phase forming the „Chinese script" precipitates. The former phase is predominant in alloys of lower iron content (up to 0,5%) and occurs in the composition of α(Al)+Al_2Cu eutectic. When iron content is higher (1,0-1,5%), phases of the $Al_6(Cu,Fe)$ type prevail.

During solutioning, the precipitates from Al_2Cu phase dissolve and saturate the α(Al) solid solution with copper. In the structure appear small amounts of the Al_2Cu phase and precipitates of the ternary Al-Cu-Fe phases. Along with the increasing content of iron in the alloy decreases the degree of the solid solution saturation with copper and increases the content of non-dissolved intermetallic phases of Al-Cu-Fe. Both these factors decide about the final mechanical properties of alloys after dispersion hardening.
As an example, Figures 1 and 2 show the effect of iron content on R_m and A_5 of AlCu4 (Fig.1) and AlZn5Mg3Cu (Fig.2) alloys.

From the investigations it follows that higher content of iron (>0,5%Fe) exerts a very obvious effect on the hardening process; increasing iron content in the alloy prolongs the time required to obtain maximum tensile strength and hardness.

To evaluate the possibility of compensating the adverse effect of high iron content, studies were conducted to know what influence various elements introduced in small amounts may have on the structure and mechanical properties of alloys in initial (as-cast) condition and after dispersion hardening.

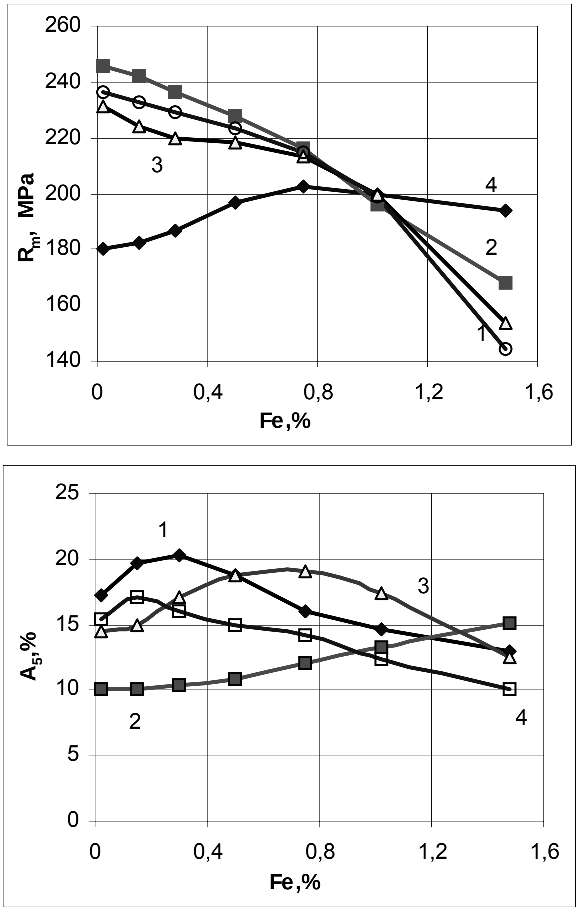

Fig. Fig 1. Effect of variable content of iron additions and solutioning parameters on the mechanical properties of AlCu4 alloy after solutioning at 798 K/48 hours: curve 1- castings in as-cast condition; curve 2- after solutioning for 8 hours, curve 3- after solutioning for 24 hours, curve 4- after solutioning for 48 hours

3.2. Effect of selected microadditives on the properties of dispersion hardened alloys

Microadditives were introduced to liquid base alloys either in pure form (Sn, Cd, In, Mg ,Zn, Sb) or in the form of proper master alloys (other elements). From these alloys, specimens were cast in metal moulds preheated to a temperature of 493K to be used in mechanical tests, measurements of hardness and microstructural examinations. The specimens were next subjected to a solution heat treatment conducted as a one- or multi-step process. After solutioning the specimens were aged at temperatures of 393 K and 433 K for the time from 0,5 to 250 hours.

From the conducted studies it follows that all of the added elements raised the tensile strength Rm of dispersion hardened

AlCu6 and AlCu6Fe0,5 alloys. The highest value of this parameter and its greatest increase during the ageing process was provided by the additions of tin, cadmium and indium.

Their application in AlCu6Fe0,5 alloy enabled obtaining the tensile strength Rm>400MPa and hardness HV>130; in the case of AlCu6 alloy still higher tensile strength of 450 MPa was achieved. However, alloys with these elements were characterised by lower elongation (A_5<2-3%). Modest increase of the tensile strength gave elements, like zirconium, zinc and magnesium (Rm=396-380 MPa); the situation was similar in alloys containing titanium, silver and antimony (R_m=360-380 MPa). Alloys with these elements were also characterised by elongation higher (A_5>5%) than the one obtained in alloys containing cadmium or tin. Relatively low level of tensile strength offered alloys with an addition of manganese, mainly because higher temperatures of the solutioning were required. The effect of nickel and chromium is rather insignificant.

The elements used in the investigations change the kinetics of alloy hardening during ageing. An analysis of the run of the curves illustrating changes in hardness HV has proved that the strongest effect on the kinetics of hardening offer microadditives of cadmium, tin and indium, of weaker effect are the additions of silver and magnesium, while the weakest effect have the additions of zinc and antimony. In the case of cadmium and tin, the process of alloy hardening was obviously speeded up when higher temperature of the ageing treatment was applied, i.e. 433K; at ambient temperature the ageing was impeded. Both these elements considerably reduced the time of ageing necessary to obtain maximum hardening.

Table 1
Maximum mechanical properties obtained after dispersion hardening in metal mould castings from AlCu6 alloy with different iron content

Fe content,%	Mechanical properties of alloys			Parameters of dispersion hardening	
	R_m, MPa	A_5, %	HV	solutioning	ageing
0.02 - 0.05	340-360	4.0-5.0	125-135	778K/12-14h	393K/60-70h
0.35 - 0.6	340-350	3,0-5,0	130-140	778K/18-24h	393K/90-100h
1.0 - 1.15	280-305	3,0-6,0	80-85	778K/22-26h	393K/120-130h
1.4 - 1.5	160-180	5,0-6,0	50-70	778K/12-16h	393K/140-150h

Table 2
Effect of tin on the mechanical properties of dispersion- hardening AlCu6FeSn alloys with varied iron contents and with additions of nickel, chromium and zirconium

No	Alloy composition						Casting process	Mechanical properties				
								R_m max MPa	A_5 max %	HV max	Dispersion hardening effect	
											ΔR_m	ΔHV
1	6.00	0.03	-	-	-	0.10	Lk	481	1.5	160	230	100
							Lp	331	1.0	170	141	107
2	5.90	0.60	-	-	-	0.15	Lk	400	2.0	133	200	68
							Lp	270	1.0	130	100	68
3	6.00	1.70	-	-	-	0.12	Lk	370	1.8	120	188	58
4	5.70	0.51	0.40	0.21	-	-	Lk	345	3.5	135	110	66
5	5.72	0.48	0.41	0.20	-	0.18	Lk	420	2.5	152	230	82
6	5.90	0.07	0.33	0.27	0.21	0.11	Lk	450	1.5	160	209	96
							Lp	360	1.6	158	128	93
7	5.83	0.40	0.40	0.25	0.23	0.18	Lk	445	1.5	152	213	88

The beneficial effect of tin and cadmium on the tensile strength of the dispersion hardened AlCu6 alloy is also visible in alloys with higher content of iron and in alloys containing, besides iron, also metals characterised by low diffusion rate in aluminium (Ni,Cr, Zr). This is illustrated by the results of investigations compiled in Table 2. They indicate, moreover, that the effect of dispersion hardening (increase in the values of Rm and HV compared to the as-cast condition) decreases with increasing content of iron in the alloy. The effect of hardening is less noticeable in castings poured into sand moulds than it is in metal mould castings.

Observations under the microscope have revealed that some of the elements present in the alloys, namely manganese, chromium and nickel, change the shape of the precipitates of the intermetallic iron-bonding phases. Acicular precipitates, typical of the AlCu6Fe0,5 alloys in as-cast condition, are replaced by the precipitates of more compact structure. Other elements do not change the morphology of iron-containing phases.

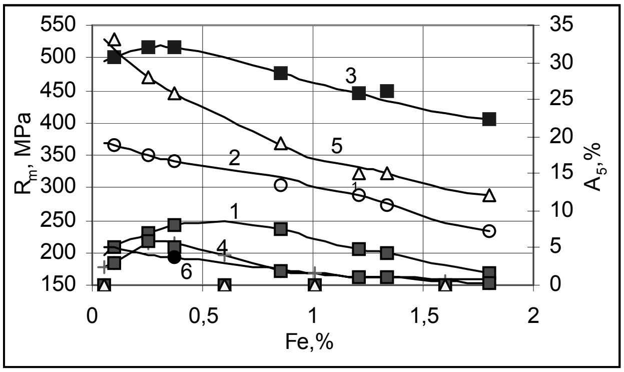

Fig.3. Effect of variable content of iron additions and dispersion hardening parameters on the mechanical properties of Al-Zn5Mg3Cu alloy after solutioning at 753K/48 hours: curve 1- as-cast condition; curve 2 – after solutioning, curve 3- after solutioning at a temperature of 403K (curve 1,2,3 – tensile strength R_m , curve 4,5,6 – elongation A_5)

4. Summary

The obtained results of the investigations can be summarised in the following way:

1) An addition of iron to Al-Cu alloys has a significant effect on the run of the dispersion hardening process and on the output of heat treatment;
2) With increasing content of iron the effectiveness of the heat treatment, expressed as an increase of mechanical properties, decreases;
3) Increasing content of iron in the alloy prolongs the time of solutioning and ageing treatment, necessary to achieve the highest mechanical properties;
4) Small additions of elements, like Sn, Cd, Mn, Zr, Ti introduced to the chemical composition of iron-containing Al-Cu alloys increase the tensile strength and hardness. Most effective in this respect has proved to be the use of cadmium and tin; less effective are the microadditives of manganese, zircon and magnesium; the least effective is the application of nickel and chromium;
5) The elements used in the present investigations influence the kinetics of the precipitation process, and the consequence are different parameters of the artificial ageing, necessary to obtain maximum mechanical properties of alloys. The strongest effect in accelerating the process of artificial ageing have the addition of tin, cadmium and indium, specially at higher temperatures of this treatment.

References

[1] L.F.Mondolfo, Aluminium Alloys Structure and Properties, Izd. Metałłurgia, Moscow 1979

[2] G.B. Stroganow, Wysokoprocznyje litiejnyje aluminiewyje spławy, Izd. Metałłurgia, Moscow 1985

[3] N.S. Postnikow, Uprocznienije aluminiewych spławow i otliwok. Izd. Metałłurgia, Moscow 1983.

[4] S.Rzadkosz, L.Staszczak, M Kucharski, Wpływ żelaza na efekt przesycania stopu AlCu4, Proceedings of IV Symposium on “Structural transformations in cast alloys. The theory and practical outcome ", Rzeszów 1989, p.229-237

[5] S.Rzadkosz, C.Adamski, J.Wąsik, Dyspersyjne utwardzanie wysokowytrzymałych stopów na osnowie aluminium. Proceedings of III Symposium on "Structural transformations in cast alloys. The theory and practical outcome ", Rzeszów 1989, p.115-120

[6] S. Rzadkosz, L. Staszczak, C. Adamski, Wpływ składników stopowych i parametrów obróbki cieplnej na strukturę i właściwości wytrzymałościowe odlewniczych stopów Al.-Zn-Mg, Proceedings of V Symposium on "Structural transformations in cast alloys. The theory and practical outcome”, Rzeszów 1993, p.95-102

[7] S. Rzadkosz, L. Staszczak, Wpływ pierwiastków modyfikujących strukturę na efekt utwardzania dyspersyjnego stopów aluminium, Krzepnięcie metali i stopów, no. 33, 1996, p.119-126

[8] S. Rzadkosz, C. Adamski, L. Staszczak, Zink-Magnezium und Kupferbedeuntung bei den Gussl;egierungem Al.-Zn-Mg, Archives of Metalurgy, v.43,1,1998, p.