THE EFFECT OF RARE EARTH METAL MINOR ADDITION ON STRUCTURE AND PROPERTIES OF Al-Zn-Mg-Cu ALLOY

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Abstract

The results of studies concerning the effect of a minor addition of a rare earth metal (REM) on grain structure, decomposing of supersaturated solid solution of Zn, Mg, and Cu in Al, texture, mechanical fatigue and corrosion properties of Al- Zn-Mg-Cu alloy forgings are shown in the present article.

It is shown that the addition of REM and Zr leads to formation of a polygonized structure in the heat treated forging. However there is practically no crystallographic texture in a REM containing alloy. In comparison with Fe and Zr additions, a minor addition of REM decreases substantially of precipitate free zone at grain and subgrain boundaries in the artificially aged state.

Microstructural features of a REM containing forging made from provide, in comparison with Fe and Zr-bearing additions alloys, an increase in strength properties, ductility, cracking resistance (first of all in short transverse direction) and fatigue resistance.

Keywords: *Al-Zn-Mg-Cu alloys, minor elements, mechanical properties, microstructural analysis.*

Introduction

At present the mechanism of changes in properties and phase composition of Al- Zn-Mg-Cu alloys within a wide range of concentrations the main alloying elements is studied in details [1]

On the basis of the above alloying system quite a number of high strength structural alloys different in terms of combination of properties has been developed [2,3]. Minor additions of modifiers and antirecrystallyzing elements (Ti, Zr, Cr, Mn, Fe) are of great importance for these alloys [4].

Minor additions of these and some other elements made to an alloy in quantities of no more than tenths of one percent remains, side by side with optimization of production processes, one of the effective methods allowing an improvement in combination of properties of the alloys du e to control of grain structure, composition and morphology of the excess phase particles, density of distribution of the age hardening precipitates and so on.

The efficiency of a minor addition of one of REM on grain structure, fine structure (structure of precipitates) and on combination of strength, plastic, fatigue and corrosion properties of Al-Zn-Mg-Cu alloy forgings has been evaluated in the present work as against the effect of Zr and Fe additions used in production of commercial alloys.

Materials and experimental procedures.

Three alloys having similar Zn, Mg and Cu content but various minor additions were produced for studies. Each alloy was alloyed with one of the following elements: 1-Fe, 2- Zr, 3- REM.

∅ 110 mm ingots were produced in a laboratory-scale electric resistance furnace. Forgings of 60 mm in thickness were made from these ingots after homogenization. These forgings were heat treated under the following conditions – solution treatment t= 470°C, water quenching: at 20°C, two step ageing: 105°C, 8 hrs + 175°C, 8 hrs.

Examination of specimen structures was carried out by optic and transmission electron microscopy (TEM) using Neophot-38 and JEM-200LX microscopes respectively as well as by X-ray

analysis on DRON-3 diffractometer. A scanning electron microscope was used for fractographic analysis of specimens subjected to crack resistance tests (a_{19}).
Strength and plastic properties as well as crack resistance (a_{19} - V-shaped notch with crack, l/b = 0.5) were determined using standard specimens cut out in longitudinal (L) and short transverse (S-L) directions. Low cycle fatigue resistance was determined on flat longitudinal specimens at K_T = 2.6, f=3-5 Hz and σ_{max} = 156 MPa. Corrosion resistance was evaluated on ring specimens stressed in S-T direction.

Results and Discussion

Analysis of ingot microstructures shows that all studied alloys in as-cast state have a dendritic structure. One can see (Fig. 1 a, b) that the modifying effect of a REM addition is similar to that of Zr addition – the average dendritic cell size for ingots made from both alloys is the same - 150-300 μm, but it is noticeably lower than in the case of Fe-containing alloys (300-400 μm, Fig. 1c).

Comparison of a grain structure of aged forgings made from the studied alloys allows one to conclude that a mixed structure develops in the forgings. The share of the recrystallized grains does not exceed 20 and 30% in the alloys alloyed with a REM and Zr respectively (Fig. 2 a, b). Addition of Fe results in the development of a recrystallized structure, mainly - up to 80% (Fig. 2 c).

TEM examination (Fig. 3) showed that in spite of a some difference in micrograin size, forgings made from the alloys with REM and Zr additions have the same average subgrain size of about 2-5 μm and disorientation angle does not exceed 1-3^0. Subgrain boundaries are suppressed by dispersoids.

X-ray analysis of the studied alloys was carried out to identify the grain structure in terms of texture formation. It is known that in the case of aluminium alloys the main deformation texture has {112}<111> orientation, while formation of cubic recrystallization texture [5] is possible during heating.

The studies showed that in the case of a REM containing alloy sample, the ratio of intensities of diffraction maximums for $(111)_{Al}$ and $(002)_{Al}$ planes was near to the tabulated value [6], what corresponded to the textureless material.

A Fe-containing alloy sample showed a sharp increase in the intensity of $(200)_{Al}$ line and also a decrease of $(111)_{Al}$ one. This was, apparently, resulted from formation of the recrystallization texture.

Analysis of the nature of the decomposing of aluminium solid solution in grain bodies of artificially aged forgings carried out using electron microscopy technique showed that the precipitates density of the $\eta'+\eta$ strengthening phase had no sufficient difference in alloys with Fe and Zr additions and was about $2x10^{14}$ particles/cm^3. The $\eta'+\eta$ precipitation density in an alloy with a REM increased up to $3x10^{16}$ particles/cm^3. Average size of the precipitated phase particles did not depend on the type of addition and for the η and η' phases was ~ 10-15 nm and < 5 nm respectively. Precipitation-free zones near grain and subgrain boundaries were not found in alloys with REM additions, while in alloys with Fe and Zr additions the width of the above zone was 60.0-80.0 nm.

Studies of the effect of various additions on forging properties (Table 1) showed that the REM addition provided not only the maximum level of strength properties, but also promoted an improvement in ductility and cracking resistance, first of all in the S-L direction what was consistent well with the results of the fractographic analysis of specimens cut in the S-L direction and subjected to the crack resistance tests.

In the case of REM alloying the fracture had a plastic nature since the failure occured with a high local plastic deformation (Fig. 4a). As for Zr-added alloy its fracture surface became fragmented and the size of holes was smaller than that in a REM alloyed material (Fig. 4b). Flat zones of low-plastic surfaces (Fig. 4 c) were present in fractures of Fe- containing alloy specimens.

Addition of a REM also promoted an increase in fatigue resistance. At the same time all alloys had the same high level of stress- and exfoliation corrosion resistance (Table 1).

Table 1
Mechanical and corrosion properties of Al-Zn-Mg-Cu alloy with minor additions forgings after artificially age.

Properties	Direction	Additions		
		REM	Zr	Fe
UTS, Mpa	L SL	560 550	510 500	480 480
YTS,Mpa	L SL	500 480	450 440	440 440
El,%	L SL	14 8	10 6	10 6
a_{19}, J/m^2	L-T S-L	150 133	145 78	92 63
LCF, kcycles	L	230	170	130
SCC, days (σ_{max}=0,9$\sigma_{0.2}$)	S-L	>90	>90	>90
Exfoliation corrosion (point)	any	N(1)	P(1-2)	P(1-2)

Conclusion

A minor REM addition made to Al-Zn-Mg-Cu alloys provides for the optimum combination of strength and plastic properties and cracking resistance in comparison with Fe and Zr containing alloys. It is attributed to features of texture formation and the grain boundary structure.

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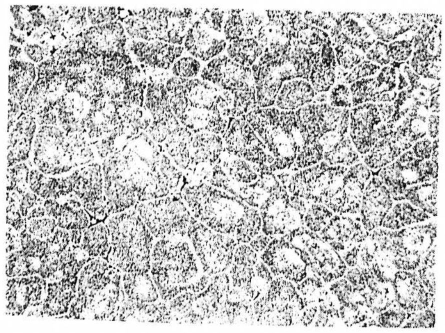
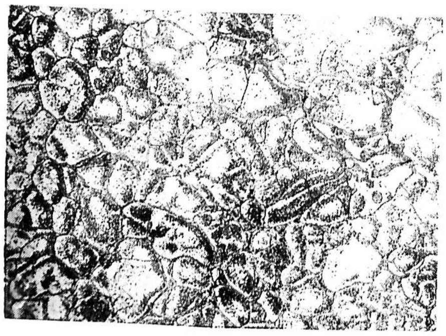
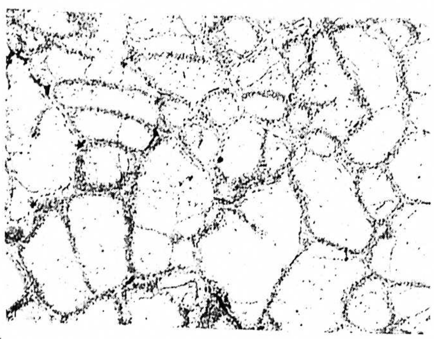


a



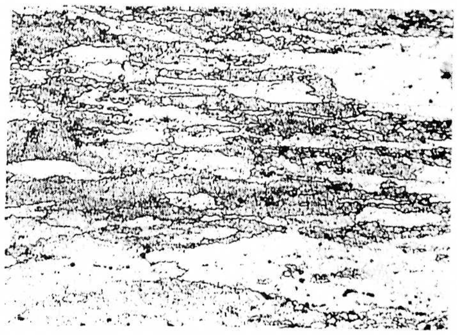
b



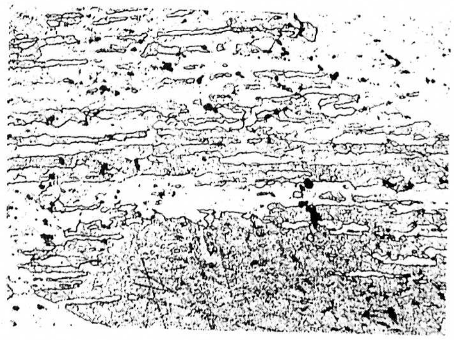
c

Fig.1 Microstructures of gomogenizated ingots from alloys containing minor additions: a – REM, b- Zr, c- Fe.

100μ m
|-------|



a



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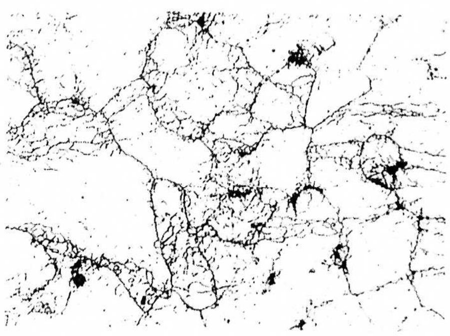

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Fig.2 Grain structure of aged forgings from minor addition containing alloys: a – REM, b- Zr, c- Fe.

200μ m
|-------|

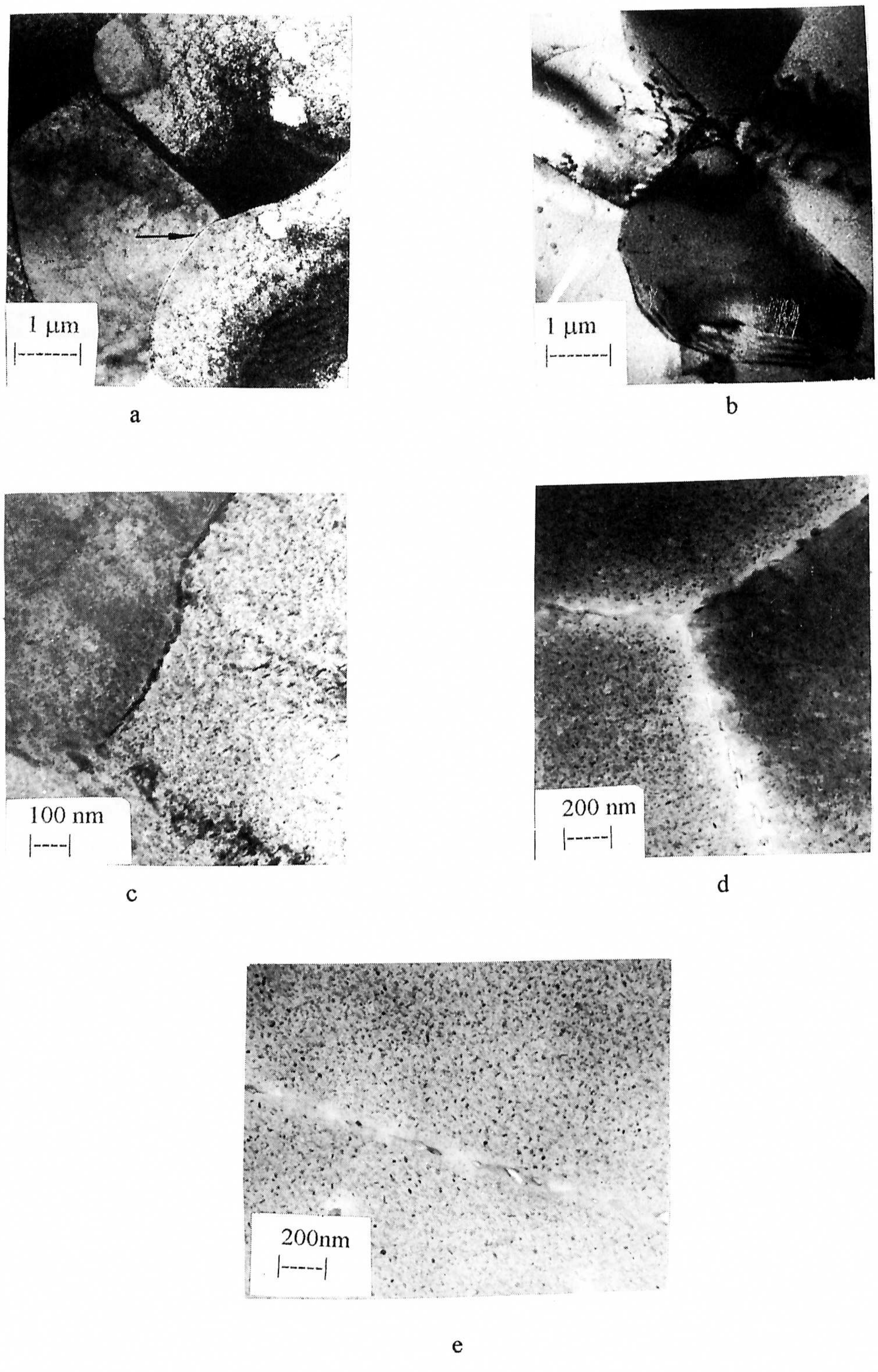
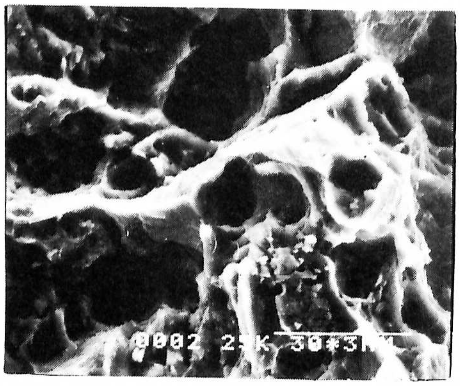
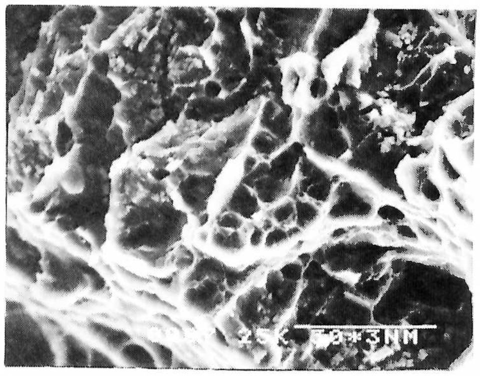


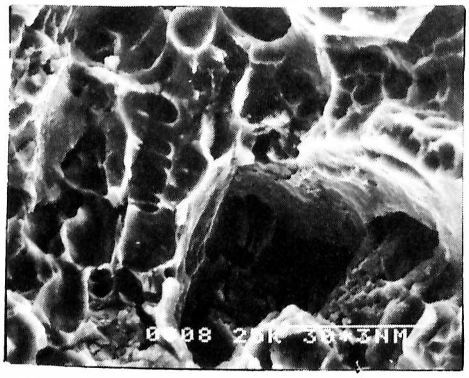
Fig.3. TEM micrograph of aged forgings containing REM (a, c) ,Zr (b, d), Fe (e) showing subgrain sizes (a, b) and η/η` - precipitates at boundaries (c, d, e)



a



b



c

Fig. 4.
SEM micrograph of fracture surfaces of a_{19} (S-T) samples containing: a-REM, b-Zr, c-Fe