Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 2405-2410

Structure and Properties of Semiproducts from Al-Cu-Mg-Ag V-1213 Alloy

Antipov Vladislav, Vakhromov Roman, Phedorenko Tatyana, Lukina Eva
All-Russian Institute of Aviation Materials, Moscow, Radio street 17, Russia

Mechanical properties and results of investigation of fine structure of rolled and extruded semiproducts from V-1213 alloy manufactured under conditions of commercial production will be given.

The alloy contains Ag addition aimed at an increase of high-temperature strength and crack resistance. Plate precipitates of thermal-stable Ag-bearing Ω-phase were formed additionally during artificial aging. Electron-microscopic analysis showed that plate precipitates of Ω-phase were coagulating in the course of long-term heats at temperatures up to 200°C, which ensured an increase in high-temperature strength.

A number of properties of V-1213 alloy semiproducts are given in comparison with those of semiproducts made from other conventional high-temperature strength alloys.

Keywords: *high-temperature strength, crack resistance, Ω-phase, rolled and extruded semiproducts, Al-Cu-Mg alloys.*

1. Introduction

An increase of high-temperature strength and reliability of wrought aluminium alloys is a vital problem of up-to-date aviation material science.

Individual areas of skin and primary structures of modern flying vehicles operate under conditions of elevated temperatures. It takes place in the engine-adjacent zones, or aerodynamic heats may be possible in case of high airspeeds.

The concept of safe damage tolerance calls for application of materials with improved fracture toughness and fatigue life combined with lowered fatigue crack growth rate.

Widely used conventional medium-strength Al-Cu-Mg alloys are of a great importance when choosing materials for airframe. For this purpose such alloys as AK4-1ch and AK4-2ch (Russia), AU2JN (France) and 2618 (USA) may be used, they however have insufficient crack resistance because of the presence of insoluble $FeNiAl_9$ intermetallics.

New Al-Cu-Mg alloy with Ag addition named as V-1213 compares favorably with AK4-1ch and AK4-2ch alloys in high-temperature strength and fracture toughness.

Iron and nickel were not used as the basic alloying elements. The alloy was alloyed with silver which has high ultimate solubility in aluminium solid solution (55.6 % wt. at 566°C) [1]. Plate Ω-phase precipitates additionally formed in the course of artificial ageing of as-quenched Al-Cu-Mg-Ag alloys strengthened the matrix [2, 3]. Lamellar Ω-phase precipitates were coagulating slowly in the course of heating at temperatures up to 200°C, which ensured an increase in high-temperature strength.

The present article gives some data on structure and basic operational characteristics of rolled and extruded semiproducts from V-1213 alloy as compared with analogues alloys.

2. Result and discussion

V-1213 alloy semiproducts were manufactured under conditions of commercial production.

Structure of sheets presented in Figure 1a was equiaxed, completely recrystallized and homogeneous as to thickness. Extruded strips had non-recrystallized structure stretched in extrusion direction (Figure 1b).

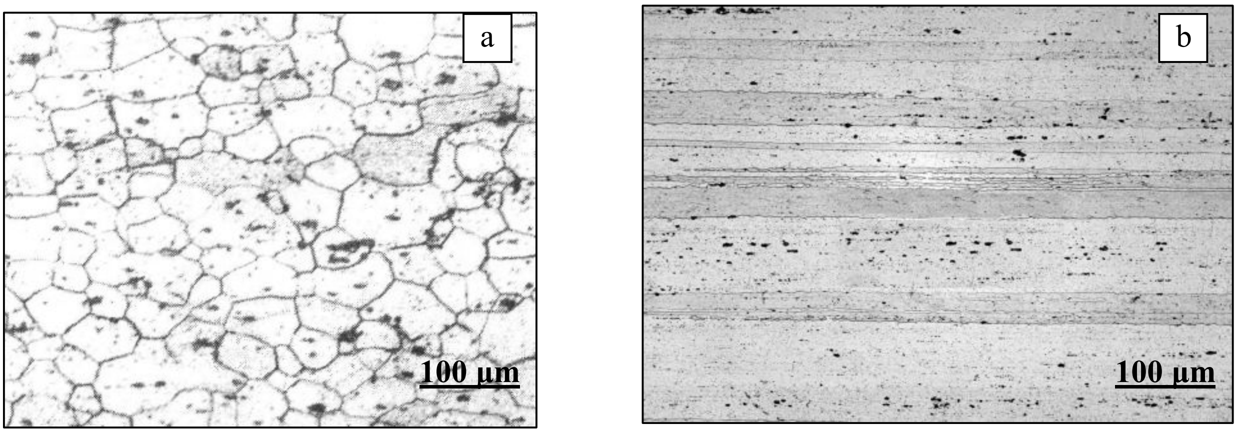

Fig. 1 – Microstructure of V-1213 alloy semiproducts:
a - sheets (SL direction); b - extruded strips (longitudinal direction)

Investigation of V-1213 alloy semiproducts microstructure in initial state T1 (ageing at 170 °C, 20 h) and after long-term heating at 150 °C, 1000 h was carried out by means of transmission electron microscopy with the help of JEOL JEM 200CX microscope.

The extruded strips had non-recrystallized structure with the subgrains size within 3-8 µm. Plate-shaped dispersoids of 0.2 – 0.6 µm in size arranged mainly along extrusion direction were observed throughout the volume of subgrains (Figure 2a).

The sheets had recrystallized structure with grain size within 20-30 µm. Grain boundaries formed equilibrium triple junctions with an angle of 120° (Figure 2b).

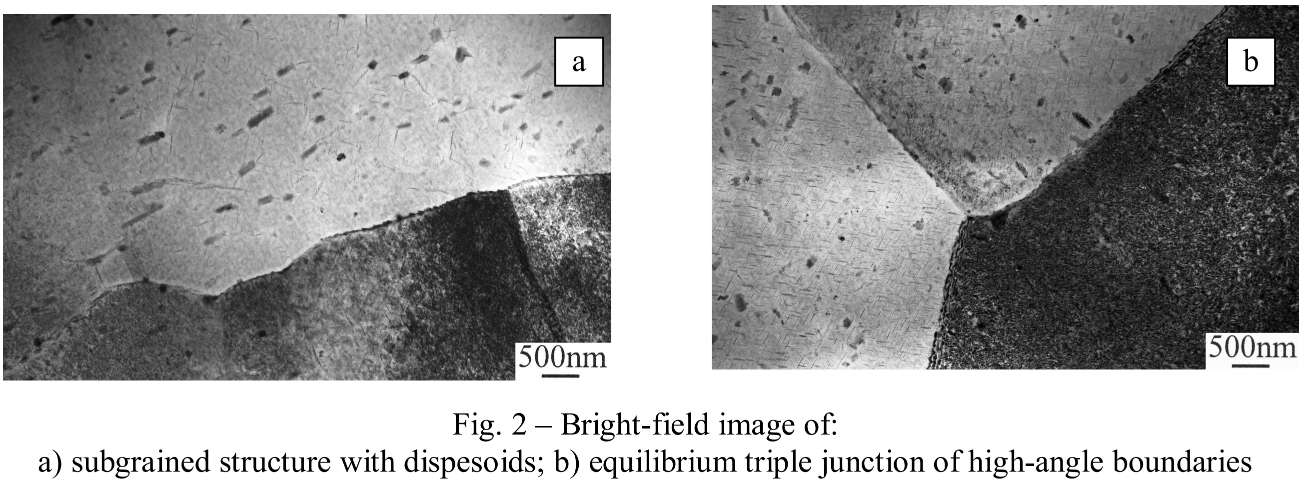

Fig. 2 – Bright-field image of:
a) subgrained structure with dispesoids; b) equilibrium triple junction of high-angle boundaries

Dispesoids (0.2-0.5 µm) were distributed throughout the volume of grains which had mainly an equiaxed shape.

Electron microscopy analysis of forging microstructure showed that the grain structure of forgings was partially recrystallized having subgrains size within 1 - 4 µm and grain size up to 8 µm.

The main strengthening precipitates in all studied semiproducts subjected to artificial ageing T1 and to long-term heating at 150 °C, 1000 h, were Ω′-phase (a type of equilibrium θ-phase (Al_2Cu) formed in the presence of silver) and θ′-phase (Al_2Cu.). Ω-phase was precipitated in the form of plate uniformly distributed throughout the volume of grains and also on sub-boundaries and high-angle boundaries forming continuous chains (Figure 3a, b). θ′-phase was precipitated non-uniformly, mainly on dislocations located inside of grains.

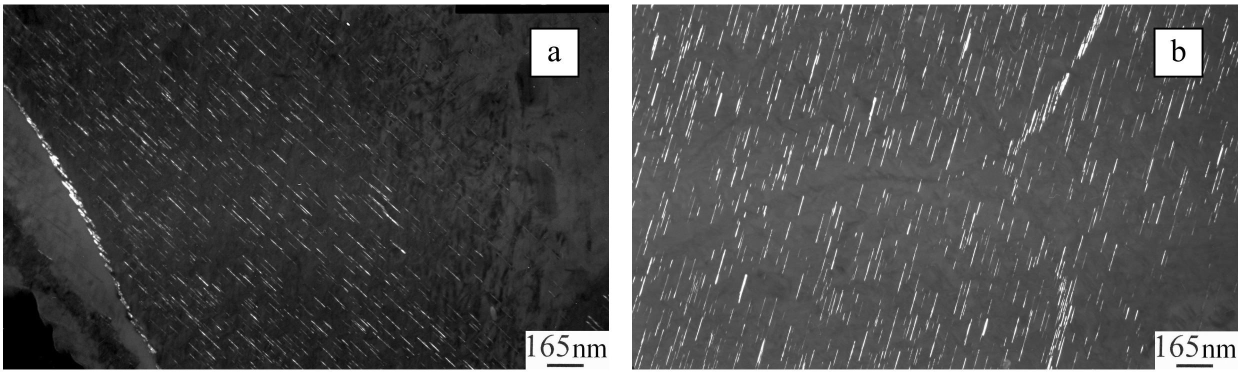

Fig. 3 – Dark-field image of Ω′-phase plates with habitus $(111)_{\alpha}$:
a) Inside of grain and along high-angle boundaries;
b) Inside of grain and along subboundaries

Heating at 150°C, 1000h caused an increase in Ω′-phase plate thickness in the extruded strips almost in 2 times (from 5,5 nanometers up to 8,5 nanometers) (Figure 4a, b). As for forgings heated at 150°, 1000 h, density of Ω′-phase precipitations was reduced due to dissolution of fine fraction and growth of a larger one. Larger plates became thicker and more stable Ω-phase (Figure 5a, b) was formed.

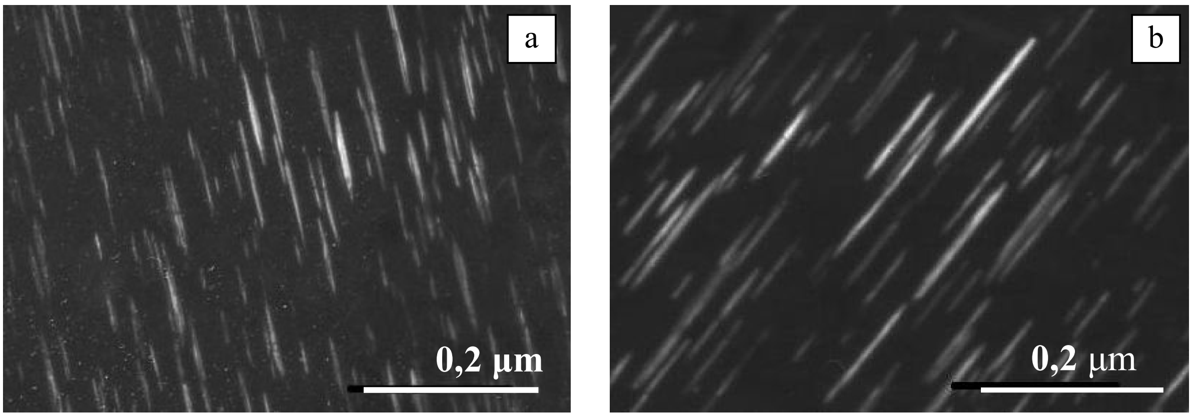

Fig. 4 - Dark-field image of Ω′- phase plates: a) T1; b) T1+ 150ºC, 1000 h

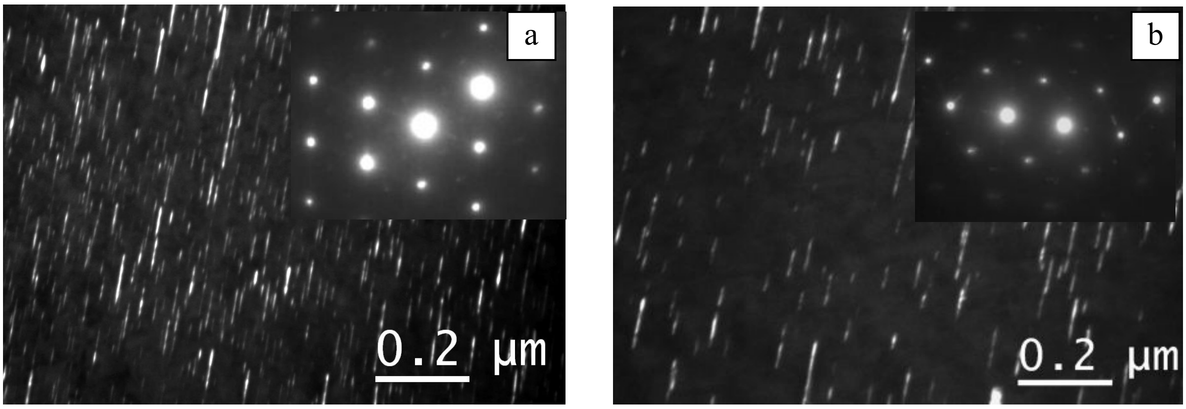

Fig. 5 - Dark-field image of Ω′- phase in forgings:
a) T1; b) T1 + 150 °C, 1000h

Thickness of Ω′- phase plates was changed a little in sheets with the time of their heating at 150 °C. Volume fraction of θ′-phases was increased in the course of long-term heating.

Long-term heating resulted also in a non-uniform precipitation of θ′-phase (Al_2Cu) throughout the volume of grain in the form of chains and separate particles (Figure 6). Precipitations of θ′-phase were not found out after T1 ageing.

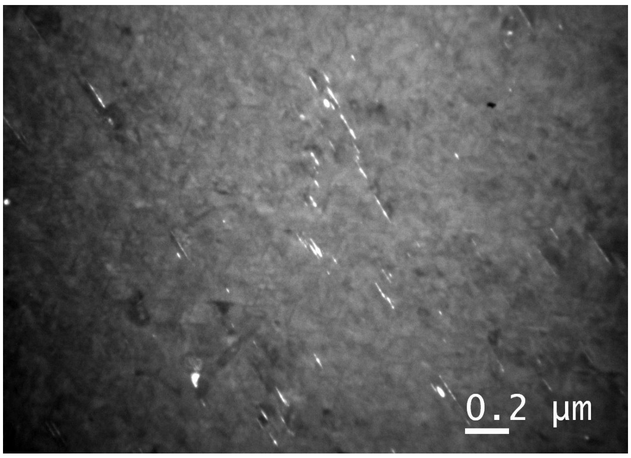

Fig. 6 - Dark-field image of θ′-phase (T1 +150°C, 1000 h)

Studies of heterogeneous precipitation occurred along high-angle boundaries showed that precipitations along grain boundaries were fine and located uniformly. Heating at 150°C, 1000h resulted in coarsening of grain boundary precipitations, formation of a precipitates-free zone about 60 nanometers in size along boundaries and also in formation of stable Ω –phase. All the above is an evidence of overageing.

Electron microscope analysis of the structure undertaken after creep tests at 150 °C, 1000 h showed, that precipitates of Ω'-phase (one of the basic strengthening phases) were in the most part monolithic and not differed from earlier investigated precipitates formed after static long-term heating at 150°C, 1000 h in terms of their volume fraction and size.

In areas close to the fracture focus, Ω′-phase plates were more fragmentized after stress rupture strength tests than after creep tests. It can be attributed to the fact that in case of strong deformation a process of slicing of large particles takes place.

Tensile properties of semiproducts at 20 °C, 150 °C and 175 °C are given in Table 1. Extruded strips and forgings have higher values of ultimate- and yield strength at 20 °C (by 15-50 MPa) caused by extrusion-effect.

Table 1 - Tensile properties of V-1213 alloy semiproducts (longitudinal direction)

Semiproducts	Test temperature, °C	UTS, (MPa)	0.2YS, (MPa)	δ, %
Sheet	20	485	435	12.0
	150	413	388	18.3
	175	397	373	19.4
Extruded strip	20	525	470	11.5
	150	415	405	16.0
	175	365	355	17.5
Forging	20	535	475	10.5
	150	425	415	15.0
	175	390	385	17.5

It should be also noted, that V-1213 alloy semiproducts have high level of fatigue life which is typical for long-life Al-Cu-Mg alloys (Table 2).

Table 2 –Crack resistance and fatigue life of V-1213 alloy semiproducts (longitudinal direction)

Semiproducts	Fatigue crack growth rate		LCF, $N_{cp.}$	
			σ_{max}	Fatigue life, kcycles
	ΔK, MPa√m	dl/dN, mm/kcycle	(MPa)	K_t = 2,6; R=0.1 f=40 Hz
Sheet	21.7 31.0	1.10 2.67	160 200	155 70
Extruded strip	21.7 31.0	1.47 2.91	160 200	158 75
Forging	21.7 31.0	1.25 3.18	160 200	276 118

Fracture toughness of V-1213 alloy semiproducts was higher than that of AK4-1ch and AK4-2ch alloys by 30-40 %. Rather low fatigue crack growth rate in sheets, strips and forgings from V-1213 alloy should be noted as well.

High-temperature strength of V-1213 alloy semiproducts is higher than that of AK4-1ch and AK4-2ch alloys [3-5] by approximately 30-40 % (Table 3).

Table 3 – Comparison of high-temperature strength of V-1213, АК4-1ch and АК4-2ch alloys

Properties	V-1213T1			АК4-1chT1			АК4-2chT1	
	Sheet	Strip	Forging	Sheet	Strip	Forging	Sheet	Strip
UTS, MPa	485	525	535	390	390	390	390	410
0.2YS MPa	435	470	475	370	325	275	370	355
UTS^{150}, MPa	390	405	420	365	370	-	365	360
$UTS_{0.2/100}^{150}$, MPa	335	335	325	225	235	-	225	265
K_c^y, MPa√m (W=100 mm)	70	66	36*	43	-	25*	57	-

* K_{1C}

Conclusions

Electron microscope analysis carried out with the help of JEOL JEM 200CX electronic microscope showed the following:

- Extruded have non-recrystallized structure with subgrain size of 3-8 μm; arranged mainly along the extrusion direction plate dispersoids of 0,2 - 0,6 μm in size are visible throughout the volume of subgrains. Structure of sheets is recrystallized with grain size of 20-30 μm. Grained structure of forgings is partially recrystallized, subgrain size is within 1 - 4μm and grain size - up to 8μm;
- The basic strengthening phase for all investigated materials is Ω'-phase. Precipitates of this phase are distributed uniformly throughout of the volume of grains and on subborders. After ageing under T1 conditions, an intensive precipitation accompanied with formation of Ω'-phase inside of grains is observed;
- Long-term heating (150°C, 1000h) leads to a decrease of Ω'-phase precipitates density due to dissolution of fine fraction and growth of a larger one. Larger plates become thicker and stable Ω-phase is formed.

As compared with АК4-1ch and АК4-2ch alloy semiproducts, advantages of V-1213 alloy semiproducts are as follows: improved characteristics of strength (by 20-40 %), high-temperature strength (by 20-40 %) and crack resistance (by 30-40 %).

New heat resistant V-1213 alloy is recommended to be applied instead of АК4-1ch and АК4-2ch alloys for heated areas (up to 150 °C) of skin and primary structures of flying vehicles.

References

[1] L.F. Mondolfo: Structure and properties of aluminium alloys, Transl. from English, (Metallurgia, Moscow, 1979) 640 p.

[2] I.J. Polmear: Proc. of the 9th Int. Conf. on Aluminium Alloys, ed. J. Nie, A. Morton and B. Muddle, (Institute of Materials Engineering Australasia Ltd, 2004) pp. 1-14.

[3] I.N. Fridlyander, V.V. Antipov, N.I. Kolobnev, E.G. Yakimova: «Aviation Materials», (FSUE VIAM, Moscow, 2007) pp. 172-179.

[4] O.A. Romanova: «Non-Ferrous Metals and alloys. Composite Metallic Materials, («Mashinostroenie», Moscow, 2001) pp. 78-55.

[5] «Structure and Properties of Aluminium Alloy Semiproducts» the 2nd edition, Ed. By V.I. Elagin, V.A. Livanov, («Metallurgia», Moscow, 1984) 408 p.