Advanced Russian Aluminum Alloys.

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Abstract

The main characteristics of the advanced russian aluminum alloys are described. The properties of high-strength alloys of Al-Zn-Mg-Cu system for the extruded panels, forgeable alloys and superplastic alloys with Sc are considered. The high-temperature alloys which are designed instead of AU2GN alloy for the supersonic air liners and the properties of Al-Li alloys for the skin and stringers of the fuselage, high-temperature alloys for the liquid hydrogen and oxigen tanks are given. The special alloys for the gyroscopes having the low coefficient of thermal expansion, the properties of aluminum matrix laminates reinforced with the glass fibers are considered.

High-Strength Alloys of Al-Zn-Mg-Cu System.

V96c3 alloy having the strength of 650-700 MPa had been developed and is using in Russia from 1965 as different semiproducts. This alloy is designed for the upper wing panels (in form of the plates and panels), for the airframes of solid-propellant rockets, etc. (See Table 1.)

Table 1. Typical Properties of Al-Zn-Mg-Cu High-Strength Extrusions

Alloy	UTS	YTS	El	K_c*	LCF	EC	SCC
	MPa		%	MPa$\sqrt{m}$	N.kcycle (σ_{max}=158 MPa)	Code	MPa
V95ochT2 (7475T76 Type)	560	510	12	130	200	2-4	172
V96c-3T2 **	610	580	10	109	200	3	167
T12	660	630	10	109		3-4	117

* W=500 mm

** Patent SU N346369, 23.11.70.

Forgeable 1933 alloy with strength of 520-540 MPa possesses the high toughness and corrosion resistance. (See Table 2.)

Forgeable 1981 alloy containing Sc has the increased characteristics of a fracture toughness. (See Table 3.)

The sheet high-strength 1987 alloy with Sc has a property of superplasticity. (See Table 4.)

Table 2 . Mechanical Properties of 1933T22 Die Forgings

Thickness mm	Direction	YTS MPa	UTS MPa	El %		K_{1c} MPa√m
20-30	L	483	533	12,0		
	L	477	518	12,0		
	LT	440	495	9,0	(L-T)	34,8
	LT	457	525	9,0		34,4
	ST	451		7,5		35,3
	ST	490		9,5	(S-T)	22,4
100-150	L	476	505	11,2		
	L	474	513	12,0		
	L	519	547	12,0		
	LT	478	518	11,2		
	LT	479	507	6,8		
	LT	471	501	6,0		
	LT	473	514	10,0		
	ST	486	516	4,0		
	ST	486	507	2,8		

Table 3. Properties of High-Strength Forgeable Alloys (for Hand Forgings of 100mm Thickness)

	Direction	Alloy and Heat-Treatment Conditions						
		V95pch		1933			01981	7050
		T2	T3	T2	T3	T22	T2	T7452
UTS, MPa	L	441	412	490	441	520	530	490
	ST	441	412	461	432	500	520	460
YS, MPa	L	412	333	441	383	451	461	420
	ST	412	333	432	363	441	451	380
El, %	L	8	9	7	8	10	10	7
	ST	3	4	3	3	5	5	4
K_{1c}, MPa√m	L-T	31	34	39	44	37	44	29
	S-L	20	23	25	25	22	31	24
SCC, σ_{cr}, MPa	S-L	196	296	172	245	172	172	245

Table 4. Superplastic Characteristics of 1987 Sheets

Alloy	El ,%	e,c^{-1}	T, ° C
Al-Zn-Mg-Cu-Sc-Zr (1987)	600	10	450 - 475

The corrosion-resistant medium-strength V91 alloy possesses high fatique characteristics, high fracture toughness and low fatique crack propagation rate. (See Table 5.)

Table 5. The properties of V-91 Alloy for the Blades of Aircraft Propellers ($d=2,72g/sm^3$)

	UTS MPa	YTS MPa	El %	FCPR mm/kcycle	K_{1c} MPa√m	Corrosion Fatique MPa at 2×10^7 cycles σ	σ^n	SCC MPa	ES code
L	440	380	12	0,27	-	270	150	90	1-2(N)
L-T	440	370	8	at $\Delta K=80$					
L-T					40				
S-L					35				

High-Temperature Aluminum Alloys.

1143 alloy of Al-Cu-Mg-Fe-Ni system (Franch mark AU2GN) has the increased fracture toughness and the lower density than AK4-1 alloy at the same high-temperature strength (See Table 6.)

Table 6. Mechanical Properties of High-Temperature 1143 and AK4-1ch (AU2GN) Alloys

Property	Plate of 65mm Thickness 1143 ($d=2,76g/sm^3$, E=72000 MPa) L	LT	ST	AK4-1ch ($d=2,8g/sm^3$, E=72000 MPa) L	LT	ST
UTS, MPa	430	420	400	440	420	400
YTS, MPa	385	380	370	390	380	370
El, %	11,0	10,0	5,5	8,5	7,0	4,0
K_{1c}, MPa√m	31,5-33	27-32	22-24	24-28	19-25	17,5-20,3
FCPR, mm/kcycle						
$\Delta K=15,6$	0,6-0,9	-	-	1,3	-	-
$\Delta K=19,0$	1,2-1,5	-	-	2,6	-	-
$\Delta K=21,9$	1,95-2,05	-	-	6,8	-	-
LCF Y=5Hz $K_t=2,6$ at 160MPa N,kcycle	164	157	-	92	85	-

D21 alloy, 1215 alloy containing Ge, Al-Li-type alloys have the higher strength and high-temperature strength than 1143 alloy at the temperatures of 125-175°C and at the long-term exposures. (See Table 7.)

Table 7. Mechanical Properties of High-Temperature Aluminum Alloys (For the Plates and Extruded Rods)

Alloy	20 °C			K_{1c} MPa√m	LCF at160MPa Kt=2,6 Y=5Hz N, kcycle	Creep Resistance and Rupture Stress 125°C,2000h		150°C,100h		175°C,100h		175°C,1000h	
	UTS MPa	YTS MPa	El %			MPa							
AK4-1 (AU2GN) d=2,80g/sm^3	430	380	9	24-26	93	200	210	250	280	210	240	130	170
1143 d=2,70g/sm^3	430	380	12	31,5-33	164	200	220	250	280	210	240	130	170
D21 d=2,84g/sm^3	460	390	13	31-32,5	150	240	280	280	310	230	270	175	220
1215 with Ge d=2,841g/sm^3	500	420	10	32-36	160	-	-	360	380	300	320	230	250

Powder high-temperature alloys of Al-C and Al-Fe-X systems are designed for the using at 300-500°C. (See Figure 1 , Table 8.)

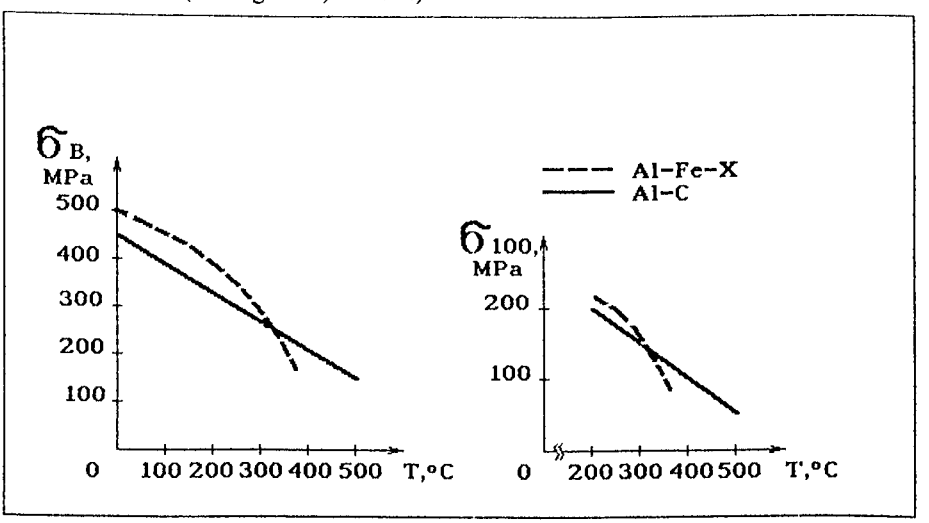

Figure 1. The Mechanical Properties of Powder Alloys.

Table 8 . Mecanically Alloyed Dispersion Strengthened Alloy 1049

Mechanical Properties	Test Temperature, °C						
	-70	20	300	350	400	450	500
UTS, MPa	480	450	225	195	155	120	110
YS, MPa	420	380	190	170	150	115	95
El, %	3,5	7,5	8,0	7,5	5,5	4,0	2,5
UTS, 100h, MPa	-	-	130	120	90	70	-
YTS, 100h, MPa	-	-	80	70	60	40	-
UTS, 500h, MPa	-	-	95	85	65	40	-
YTS, 500h, MPa	-	-	70	60	50	35	-

The Aluminum-Lithium Alloys.

The lightest corrosion-resistant weldable 1420 and 1421 alloys of Al-Li-Mg system are used for the propellant tanks, nose parts of rockets, fuselage stringers, cockpits, etc. 1421 alloy containing Sc has the higher yield strength. (See Table 9.)

Table 9. The Properties of Aluminium-Lithium 1420 and 1421 Alloys

Property	1420 (Al-5Mg-2Li-0,1Zr) d=2,47g/sm^3						1421 (Al-5Mg-2Li-0,15Sc-0,17Zr) d=2,49 g/sm^3		
	sheet RX 1,2-3,0mm		sheet unRX 1,2-2,5mm		weldment		sheet 4,0mm		weldment 2,0-4,0mm
	L	T	L	T	RX	unRX	L	T	
UTS, MPa	430	440	480	475	370	360	460	480	360
YTS, MPa	270	270	275	280	-	-	320	340	-
El, %	11	13	12	12	-	-	6	13	-
K_c^{app}, MPa$\sqrt{m}$ B=200mm	70	-	65	-	70	-	68	62	50
LCF, 160MPa, kcycle	105	145	130	120	180	260	-	100	110
FCPR, mm/kcycle									
Δ K=15,6 MPa							1,25	1,9	
ΔK=25,0 MPa							2,6	6,2	
Δ K=31,3 MPa	1,9	-	5,2	-	3,7	7,0	-	5,5	
SCC, MPa	250		250				300		

The structural 1441 and 1430 alloys of Al-Li-Mg-Cu system are designed in place of D16 (2024) alloy, they possess high structural characteristics. 1441 alloy allows to carry out the coil cold rolling without the process annealings to the thickness of 1,0-0,6 mm. (See Table 10.)

Table 10. The Properties of Aluminium-Lithium 1430, 1441 and 1451 Alloys

	1430 (Al-Cu-Mg-Li-Zr)				1441 (Al-Cu-Mg-Li-Zr)		1451 (Al-Cu-Li-Zr)			
Alloy	E=79000 MPa				E=78500 MPa		E=79500 MPa			
	d=2,57 g/sm^3				d=2,59g/sm^3		d=2,63g/sm^3			
Semiproduct	sheets 1,2-2,5mm coil rolling				sheets 1,2-2,0mm		sheets 2,0-5,0 coil rolling			
Direction	L		T		L	T	L		T	
Structural State	RX	unRX	RX	unRX			RX	unRX	RX	unRX
UTS, MPa	435	450	435	440	425	420	470	520	460	490
YTS, MPa	315	350	300	340	325	305	420	460	400	440
El, %	21	13	20	14	16	16,5	10	10	9	9
K_c^{app},MPa$\sqrt{m}$										
B=200mm	79	-	82	79	-	-	82	76		
400mm	-	102	-	-	-	101	-	-		
500mm	110	-	-	-	105	-	-	-		
LCF,160MPa										
kcycle	150	180	175	180	182	175	120	170		
FCGR, mm/kcycle										
ΔK=31,3MPa$\sqrt{m}$	2,4	2,3	2,2	2,0	1,9	1,8	4,0	5,3		
SCC, MPa	>150		>150				>150			

High-strength 1450 alloy of Al-Li-Cu system could be used for the thin sections instead of V95 (7075) alloy.
The weldable cryogenic 1460 alloy is intended for the liquid hydrogen and oxigen tanks instead of 1201 (2219) alloy (See Table 11).

The Structural Alloys of Duralumin-Type - D16 (2024).

1161 and 1163 alloys have low fatique crack propagation rate and high low-cycle fatique (See Table 12).

The Composite Laminate SIAL of GLARE-Type.

The laminate composed of the thin sheets of D16, V95 (2124, 7175) alloys and the high-strength, high-modulus glass fibers show high specific strength and low fatique crack growth rate. It is designed for the fuselage skin especially for the zones of the acoustic loads. (See Table 13.)

Table 11. The Properties of 1460 Alloy (d=2,6g/sm^3; E=81000 MPa)

Semiproduct, Test Temperature, K	Direction	UTS MPa	YTS MPa	El %	LCF kcycle	FCGR, mm/kcycle ΔK=16MPa√m
Sheet 6,0 mm						
293	L	560	515	6,0	200	0,29
	T	560	510	8,0	210	
77	L	605	550	5,0		0,28
	T	605	550	5,0		
20	L	700	555	10,0		0,33
	T	680	570	7,5		
Weldment						
293		300			250	0,35
77		380				
Extrusion 5,5 mm						
293	L	550	490	7,5	160	0,45
	T	580	505	6,5		
77	L	600	550	7,5		0,43
20	L	720	570	9,5		0,48
Weldment						
293		325				

Table 12 . Properties of 1161T and 1163T.T7 Plates

Property	Direction	1161T Plate t=25mm min-max	1163T Plate t=40-46mm min-max	1163T7 Plate t=40-46mm min-max
UTS, MPa	L	461-495	441-470	461-529
	LT	446-456	421-450	431-519
YS, MPa	L	353-377	314-343	343-412
	LT	314-323	294-323	294-372
El, %	L	16-18,5	12-20	12-24
	LT	19-21	10-19	11-21
LCF,kcycles σ_{max}=157MPa	L	280	180	200
FCPR mm/kcycles Δ K=31MPa√m	L	3,0	3,8	5,0

Table 13. The Properties of SIAL (GLADE-Type) Laminates.

Characteristic	Value
Structure	2/1; 3/2
Total Thickness, mm	0.8 - 2.5
Al sheet thickness,mm	0.3 - 0.5
UTS, MPa	700 - 1200
E, GPa	60 - 64
d, g/sm^3	2.4 - 2.5
FCPR,mm/cycle (Δ K=31 MPa$\sqrt{}$ m) W=500 mm	< 0,3
LCF, kcycle (σ_{max}=156 MPa)	200 - 1000
R_{min}	4 - 5t

The Powder Alloys for the Gyroscopes.

CAC1-400, CAC1-50 and KSP alloys having very low coefficient of linear expansion are used as the main structural material for gyroscopes (See Table 14).

Table 14. Properties of Powder Aluminum Alloys

Alloy	UTS,MPa	YTS,MPa	E,GPa	El,%	d,kg/m^3	10^{-6},grade^{-1} (20-100°)
CAC1-400	260	180	90	2,5	2720	15
CAC1-50	320	190	105	2,0	2720	15
KSP-15	330	230	120	1,0	2650	13