UNIVERSAL STRUCTURAL WELDABLE ALUMINIUM ALLOY 1151 WITH IMPROVED CORROSION RESISTANCE FOR OPERATION AT ELEVATED AND CRYOGENIC TEMPERATURE

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ABSTRACT Some semifinished item and weldable alloy 1151 properties complex at room, elevated and cryogenic temperature is represented. Alloy 1151 advantages in comparison with present aluminium structural alloys, and possible fields of this alloy application are shown. Semi-product types manufactured of alloy 1151 by industry are mentioned.

Keywords: *aluminium, structural, alloy 1151, corrosion resistant, high-temperature resistant, weldable, cryogenic, mechanical properties, Al-Cu-Mg.*

1. INTRODUCTION

Up-to-date development of aerospace engineering takes place in direction of expansion of supersonic aeroplanes use for passenger and cargo transportation, for creation of powerful carrier rockets for different purpose sonde and satellite commercial launches, for creation of scientific orbital space manned probe units, and for transport and cargo space vehicles. Incidentally, aluminium alloys remain one of the main structural materials, but much more increased and strict demands are made for their operating characteristics and reliability. First, it is related to expansion of operating range of temperatures, and to its influence on alloys. Second, it is related to considerable increase of new structures manufacture and use cost.

In addition to traditional strength properties of alloys, of special importance are such characteristics as high-temperature resistance, corrosion resistance, fatigue, ductility, cryogenic properties, weldability, adaptability to manufacture, and possibility to produce more semiproducts of different types of one and the same alloy.

For many widely used and new aluminium alloys, alloy decreased corrosion resistance at influence of operating heating and, as a result, impossibility to realize completely the alloy intrinsic characteristics, may become the factor which restricts the alloy successful use for new types of aerospace structures.

The other factor, which complicates aluminium alloy use and influences aerospace articles manufacture and use, is relatively narrow specialization of some alloys on their purpose and on possibility of semiproducts production of them. It results in increase of the range of alloys in the structure, but such an increase results in decrease of the structure adaptability to manufacture and makes the structure more expensive.

Creation of multi-purpose, multi-function structural aluminium alloy with increased corrosion resistance, high-temperature resistance, and good adaptability to manufacture, which can replace several alloys in the structure, is a problem which was successfully solved by VIAM specialists.

2. RESEARCH TECHNIQUE

Before the work was started (1972) on development of new aluminium superalloy, in the USSR and in the leading countries of the world, in addition to the existing alloys of Al-Cu-Mg system (Д16

- USSR; 2024, 2124 -USA) new alloys appeared of Al-Cu-Mn system (Д20, Д21 - USSR; RR57, RR58 - UK), of Al-Cu-Mg system (M40, ВАД-1 - USSR), of Al-Cu-Mg-Fe-Ni system (AK4-1 - USSR; 2618 -USA), etc.

Our own great experience and analysis of alloy characteristics and research results published by then enabled to make some conclusions including the following: of two main dispersed diffusion movable phases θ (Al_2Cu) and S (Al_2CuMg), S phase increases alloy high-temperature resistance more considerably. So for new superalloy composition development, Al-Cu-Mg system was selected. It should be noted that in the USSR (including VIAM), great attention was traditionally paid to this system research. So for example, despite the wide world opinion concerning unweldability of alloys of "duralumin" type , in the USSR, on the basis of Al-Cu-Mg system, for the first time weldable superalloy compositions were developed - M40 [1] and ВАД1, which later were used for new types of rockets. However, the further experience of the work with these alloys revealed some peculiarities which complicate wide use of them.

For development of new weldable superalloy adaptable to manufacture, in 1972-1987 VIAM conducted deep complex research of aluminium angle of Al-Cu-Mg system and model alloys. Influence of the great number of alloying additions on investigated model alloy characteristics change was studied. Special attention was paid to detailed investigation of hot-shortness [2, 4] and fluidity [3] values distribution in aluminium angle of Al-Cu-Mg system, because research results available by then [5, 6, 7] were not able to give synonymous answer to the put question. The work was conducted using the method of experiment planning (Scheffe simplex-plans) in the course of "composition-properties" investigation [8]. Over 150 model alloys were investigated. Semiproduct laboratory and industrial lot long-term investigations resulted in development of some new weldable superalloys: 1150, 1151, 1153, and 1177. Incidentally, special attention was paid to alloy 1151. All alloys were protected by the USSR and Russian Federation patents.

3. RESULTS AND DISCUSSION

Compared to the existing aluminium alloys, alloy 1151 is characterized by some substantial advantages. Alloy 1151 good adaptability to manufacture made it possible to master the production of all the main semifinished items: sheets (0.8 ... 7 x 2000 x 7000 mm), plates, different extruded semiproducts, forgings and die forgings of up to 120 kg weight. Besides, it enabled to produce, using cold deformation method, stamped sheet parts and, using rotational rolling in tool method, cylindrical blocks of different diameter and minimum wall thickneess up to 0.5 mm.

Alloy 1151 use in structures decreases considerably the range of alloys; in its turn it decreases labour content and financing for structure manufacture.

Another important advantage of alloy 1151 consists in unique combination of its properties: increased high-temperature resistance [9] and good corrosion resistance (especially during long-term temperature effect), good weldability by all types of welding, high properties at cryogenic temperatures, good indices of ductility and toughness, low sensitivity to stress concentrators, high stability of properties.

The alloy is a material which is reinforced thermally: standard thermal treatment is represented by quenching and ageing at room temperature (T) and annealing (M) if necessary.

In alloy 1151 structure, the main reinforcing phases during thermal treatment are phase S, and, to a lesser extent, phase θ. As a result of alloying specificity and manufacture technology, alloy structure includes disperse intermetallic compounds which are practically motionless at operating temperature (up to 450°C).

Carefully developed relation between alloying elements and the technology of semifinished item production are the basis for original combination and stability of alloy 1151 properties, and provide optimum dispersivity, morphology and topography of reinforcer and intermetallic compound phases.

Semifinished items made of alloy 1151 (Table 1) have high strength characteristics within wide temperature range (- 196 ... 450°C, standard tests) at negligible decrease of elongation; welded joint strength is not less than 0.8 of base metal strength (at different relations between welded joint and directions of semiproduct structure); more than 200°C - welded joint is of equal strength with the main material. Semiproducts made of alloy 1151 (including large and voluminous ones) are characterized by negligible anisotropy of properties and by good ductility in up direction. In Fig.1, increased high-temperature resistance of base metal and welded joints of highly pressure-tight alloy 1151 in comparison with well-known alloy 2219 is given. Besides, alloy 1151 is characterized by decelerated loss of strength at temperature increase (Table 1, 2, 3, 4, Fig. 1), and it compares alloy 1151 favourably with the existing superalloys of duralumin type.

Table 1 *Typical mechanical properties of some semiproducts of alloy 1151T (short-term tests)*

Tempera-ture °C	Sheet t=2.5 mm				Die forging					
	LTD base metal			LD welded joint	LD			ST		
	UTS	YTS	E	UTS	UTS	YTS	E	UTS	YTS	E
	MPa		%	MPa	MPa		%	MPa		%
- 196	560	390	18.0	-	-	-	-	-	-	-
20	465	320	19.0	395	465	310	13.0	450	315	9.5
150	410	310	20.0	360	400	285	13.0	395	285	10.0
300	295	255	15.5	200	190	155	24.0	205	175	11.5
200	390	290	21.0	338	375	270	12.5	375	265	11.5
350	170	125	20.0	160	95	73	33.0	113	64	28.5
400	65	49	28.0	65	56	42	60.0	65	35	46.5
450	45	25	78.5	45	36	22	75.0	40	24	90.0

Table 2 *Elasticity modulus (E) values of alloy 1151T at elevated temperature (Ø 100 mm pressed rod; transversal direction)*

Temperature, °C	20	200	300	400
E, MPa	71550	64200	58000	48500

At cryogenic temperatures strength increase (25%) does not result in ductility decrease (Table 1). So, e.g. (Fig 2) within the range from - 196°C to 200°C, no decrease of impact strength is observed in L and TL directions of cold-rolled (2.5 mm) and hot-rolled (7 mm) sheets of alloy 1151. Some decrease of this characteristic values at 200 ... 350°C is related to decay of oversaturated solid solution and to appearance of the great number of phase S disperse precipitations - it increases matrix high-temperature resistance and is reflected on the level of values of impact strength at 300 ... 400°C. The majority of existing duralumins are characterized by solid solution decay start at lower temperature, and at 300 ... 400°C disperse precipitation intensive coagulation (especially of θ phase) and loss of strength take place. Decreased rate of alloy 1151 loss of strength at 300 ... 450°C (Table 1,2,3,4, Fig. 1,2) is also a result of presence of the smallest diffusion motionless intermetallic compound in the structure.

Table 3 *2 mm sheet and alloy 1151T mechanical properties after heatings at 125-175 ℃ (direction -T)*

Heating time, hours	Heating temperature, °C								
	125			150			175		
	Mechanical property values at 20°C								
	UTS	YTS	E	UTS	YTS	E	UTS	YTS	E
	MPa		%	MPa		%	MPa		%
100	440	315	16.0	450	335	16.0	460	420	5.5
1 000	440	328	14.5	450	420	4.0	420	355	5.0
5 000	465	425	7.0	440	415	5.0	390	325	6.0
10 000	460	430	4.5	430	370	4.5	380	315	6.0

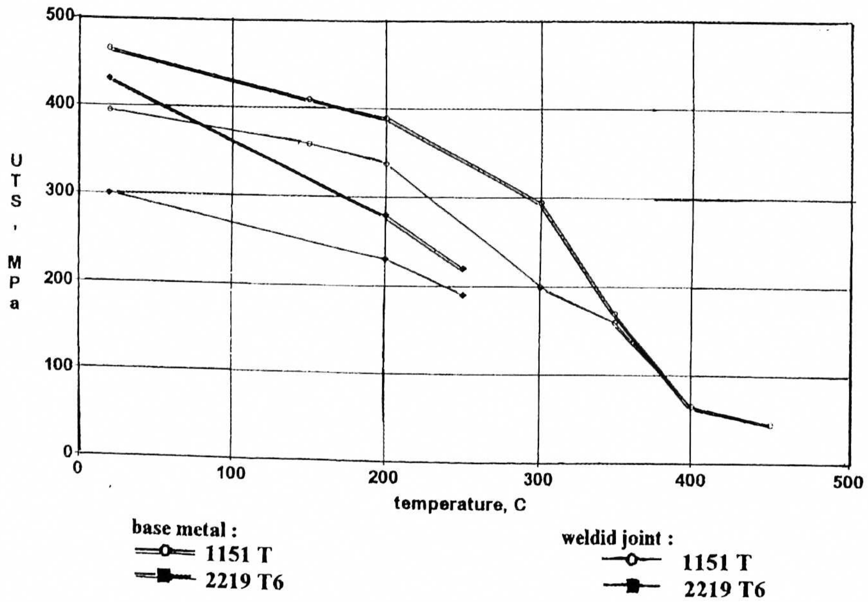

Fig I *Variation of base metal and welded joint ultimate strength for the sheets of 2-3 mm of 1151 T and 2219 T6 alloys at 20...450 °C.*

Table 4 *Alloy 1151T 3 mm sheet long-term strength values at 125-175 ℃ (direction - T)*

Temperature,°C	125	150		175
Stress, MPa	200	150	200	150
Time before rupture, hours	> 28 000	> 29 000	16 000	> 4 000

Alloy 1151 keeps high values of strength and ductility characteristics at 20°C even after long-term heating at 125 ... 175°C (Table 3). Besides, this investigation results indicate decelerated rate of alloy 1151 loss of strength at long-term effect of high temperature.

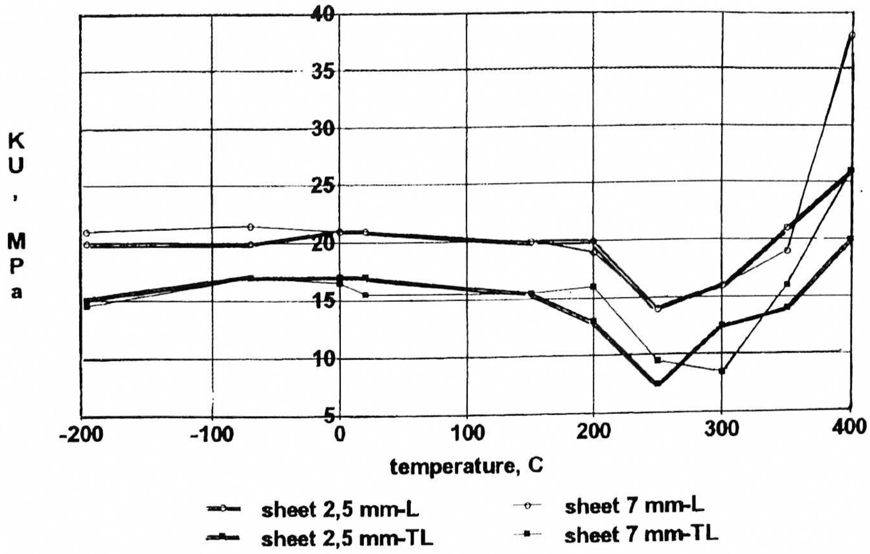

Fig 2 *Variation of impact toughness value when bending the 1151 T alloy sheets in the temperature range from -196 to +400 °C.*

Of certain interest for the specialists developing aircraft structures under heating is the alloy 1151 capability to work for a long time without failure under conditions of simultaneous influence of elevated temperature (125 ... 175°C) and stresses (Table 4). On this characteristic, alloy 1151 surpasses many aluminium alloys used in structures.

As it is mentioned above, alloy 1151 keeps good resistance against corrosion after long-term heating (e.g. at 125 ... 200°C) (Table 5); it makes it possible to realize completely alloy high properties during exploitation. This peculiarity of alloy 1151 is a great advantage compared to many aluminium alloys, which are used today, and it enables to increase structure reliability and to decrease maintenance costs.

Table 5 *Results of tests at 20 °C for delamination and intercrystalline corrosion of alloy 1151T 2 mm sheet after heating to 125-200 °C*
Initial state (T): intercrystalline corrosion - 0.0 mm; delamination corrosion - EA

Corrosion test type \ Temperature, °C		125	150	175	200
Intercrystalline corrosion, mm	1*	0.0	0.14	0.15	0.1
	2*	0.03	0.07	0.14	0.14
	3*	0.07	0.12	0.1	0.14
	4*	0.0	0.0	0.0	0.0
Delamination corrosion	1*	EA	EB	EB	EB
	2*	EA	EA	EB	EB
	3*	EA	EA	EA	EA
	4*	EA	EA	EA	EA

* Heating time, hours: 1 - 100; 2 - 1 000; 3 - 5 000; 4 - 4 000

Together with good high-temperature and corrosion-resistance properties, alloy 1151 is characterized by quite satisfactory fracture toughness and fatigue properties (Table 6) of both base metal and welded joint. 2.5 - 3 mm sheet fatigue tests verify that anisotropy is not characteristic for semiproducts of alloy 1151 (Table 1 - die forging).

The welded joint demonstrates high fatigue properties as well. In Table 6, welded joint and one or two replay welding test results are given (90 - 110 MPa). Cracking low coefficient set according to various welding tests (e.g., < 5 mm - on cross sample), welded joint good formability, and air-tightness are provided by specially developed filling wire and by thoroughly developed welding technology (which contain Know-how elements).

Table 6 *Fracture toughness and fatigue characteristics values at 20 °C for 2-3 mm sheets and alloy 1151T forging (base metal and welded joints)*

Semiproduct	Test conditions	Direction	Property
Sheet 2.0 mm	Fatigue crack growth dl/dN (for W=200 mm)		
	ΔK, MPa√m		mm/cycles
	12.4		$1.65x10^{-4}$
	18.6		$5.43x10^{-4}$
	24.8	T-L	$1.44x10^{-3}$
	31.1		$3.92x10^{-3}$
	Fracture toughness (for W=400 mm)	T-L	80.5 MPa√m
Sheets 2.5 - 3.0 mm	Fatigue, ($N=2x10^7$ cycles) a) base metal $K_t = 1.0$	L-T	tension 138 MPa
		T-L	tension 138 MPa
	b) welded joint $K_t = 1.0$	T-L	tension 90-110 MPa
Die forging	LCF $K_t = 2.2$ $R_{max} = 155$ MPa	L-T	$6x10^5$ cycles

Alloy 1151 can be used in structures (welded and non-welded) which work at elevated temperature (long-term work - up to 200°C, short-term work - up to 450°C) and at cryogenic temperature.

In 1987-1990, as a results of successful research and technological programs, alloy 1151 was used in new rocket prototypes (∅ 350 - 700 mm), and in some cases it was used instead of titanium alloys and stainless steel.

4. CONCLUSION

- New aluminium superalloy 1151 was developed for aerospace engineering structures. The alloy has no analogs.
- On its main characteristics, alloy 1151 is not worse than the aluminium alloys used today in various fields of engineering, and as for its properties combination (high-temperature resistance, corrosion resistance, weldability), the alloy surpasses many of existing aluminium alloys which are similar in use.
- Different semiproducts manufacturing of the alloy is possible; air-tight body and structure compartments welding processes are developed.
- The alloy is intended for use in aerospace and engineering industry structures (welded and non-welded) which work for a long-term (- 196 ... 200°) and short-term (up to 450°C) period at elevated and cryogenic temperature. Alloy 1151 use in the structures makes it possible to decrease financial expenses during manufacture and exploitation.

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