Product Properties of High Workability 1441 Al-Li Alloy

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Abstract

The Russian corrosion-resistant 1441 alloy is the most workable material among Al-Li alloys in terms of cold rolling. Clad sheets of 1200-1800 mm in width and up to 7000 mm in length (including some with the thickness down to 0.3 mm) are cold rolled in coils. Alloy 1441 sheets are applied in seaplanes, developed by the design office named after Beriyev, as the primary structural material. Fracture toughness, tension properties, fatigue crack growth rate (FCGR) and durability of cold rolled 1441 alloy sheets and extruded panels have been determined. Results of the tests undertaken are discussed in the present paper.

1. Introduction

Development of Al-Li structural alloys with low density and an improved elastic modulus is one of the most attractive solutions of the problem concerned with weight efficiency of flying vehicles. Among Russian Al-Cu-Mg-Li alloys, the highest degree of adaptation to commercial production is exhibited by medium strength 1441 alloy [1]. 1441 alloy demonstrates a density reduced by 6.5% (2.6 g/cm^3), an elastic modulus increased by 12% (78.4 GPa) and improved service life as compared with 1163 alloy (Russian version of USA 2524 alloy) in case of a close level of strength properties of these alloys.

Alloy 1441 provides higher workability under both cold and hot deformation, when compared with Al-Li alloys of other alloying systems [2]. An attractive combination of contents of the main alloying elements allows production of clad, cold-rolled sheets down to 0.3 mm in thickness via coil rolling technology similar to that used for production of 2524 alloy thin sheets.

Sheets having thickness more than 1.5 mm are produced via coil cold rolling of 6 mm thick sheets without intermediate annealing. In case of production of thinner sheets an intermediate annealing of coils is needed.

This alloy shows a high ductility in case of hot working. This allows production of extruded semiproducts (incl. thin-walled extruded panels) at the commercial level. Such panels are manufactured by extrusion of thin-walled ribbed tubes followed by slitting and straightening.

2. Experimental Procedure

Alloy 1441 semiproducts are quenched from 530±3^{o}C in water with subsequent 0.5-3% straightening. Ageing can be carried out under two conditions: at 150 ^{o}C, 24-30 hrs (T1) or at 150 ^{o}C, 4 hrs + 170 ^{o}C, 24-30 hrs (T11). The first type of conditions ensures higher ductility and a high level of operating reliability. The second one promotes higher strength properties, especially yield strength, at some decrease in ductility.

The present work is devoted to studies of structure and mechanical properties of sheets and extruded panels produced under commercial conditions and aged to the T1 state.

Fracture toughness of 0.8 mm thick sheets and extruded panels was determined with the usage of 200 mm (B) wide specimens and 1.5 mm thick sheets with the usage of 200-400 mm (B) wide specimens, and a geometry such that the crack length 2l = (0.3-0.4)B.

Crack resistance was studied via testing of 0.8 and 1.5 mm thick sheets and specimens cut from extruded panels. Fatigue crack development rate was measured at a maximum load as much as 100 MPa (stress ratio R=0, frequency f=5 Hz) with the usage of longitudinal and transversal specimens.

Low cycle fatigue was carried out using specimens with a hole under axial loading (K_t = 2.6; f = 40 Hz; σ_{max} = 157 MPa).

3. Results and Discussion

Structural investigations showed that the sheet structure was recrystallized partially or fully, Figure 1.

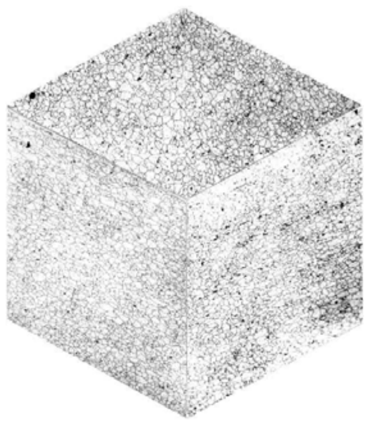

Figure 1: Typical microstructure of 1441 alloy sheets, ×50.

A non-recrystallized structure was typical for extruded panels. There was no coarse-grained zone.

Results of testing of tensile properties are given in Table 1. The sheets had a low inverse anisotropy of mechanical properties; this level was much lower than that of other Al-Li alloys. So, the variation of strength properties in longitudinal and transverse directions did not exceed 20 MPa. The difference in strength properties of specimens cut in the transverse direction and at an angle of 45^{o} was about 40 MPa and the variation in ductility was 4%.

Table 1: Tensile properties of 1441 Al-Li sheets and extruded panels.

Product	Orientation	Tensile Strength, MPa	Yield Strength, MPa	Plastic Elongation, %
Sheet	Longitudinal	415	315	16
	Transverse	430	325	14
	45°	405	280	18
Extruded panel	Longitudinal	450	360	9
	Transverse	475	390	9

A comparison of the properties of extruded ribbed panels and sheets revealed a noticeable extrusion effect. Ultimate strength and yield strength of the panels exceeded the corresponding values for sheets by 35-45 and 45-65 MPa respectively, and this was accompanied by a reduction in elongation by 5-7%. Panels showed a low anisotropy of properties. Testing of transverse specimens cut from the zones located under an rib demonstrated an insignificant decrease in strength properties (by 5-15 MPa).

Results of fracture toughness tests of 1441 alloy sheets and extruded panels are given in Table 2. Fracture toughness rose by about 25% with a doubling of specimen width. The studied sheets can be considered as isotropic in terms of fracture toughness. The values of fracture toughness obtained are correlated well with data for 1163T (T3-type) alloy alclad sheets of 2-4 mm in thickness: K_c = 97-102 MPa√m (B = 400 mm, longitudinal specimens). Fracture toughness of panels exceeded that of sheets by about 13%.

Table 2: Fracture toughness (K_c) of 1441 Al-Li sheets and extruded panels.

Product	Orientation	K_c, MPa√m	
		Sample width, mm	
		200	400
Sheet	Longitudinal	77.0	100.3
	Transverse	72.7	95.2
Extruded panel	Longitudinal	86.8	–

Fatigue crack growth rates (FCGR) of 1441 alloy sheets and extruded panels are presented in Table 3.

Table 3: Fatigue crack growth rate (d(2l)/dN) of 1441 Al-Li sheets and extruded panels.

Product	Orientation	ΔK, MPa√m	d(2l)/dN, mm/kcycles
Sheet	Longitudinal	18.6	$\frac{0.26\text{-}0.39}{0.33}$
		31.0	$\frac{1.63\text{-}4.78}{2.85}$
	Transverse	18.6	$\frac{0.26\text{-}0.30}{0.28}$
		31.0	$\frac{1.05\text{-}2.57}{1.84}$
Extruded panel	Longitudinal	18.6	$\frac{0.38\text{-}0.55}{0.45}$
		27.9	$\frac{2.96\text{-}4.62}{3.79}$
	Transverse	18.6	$\frac{0.15\text{-}0.16}{0.16}$

The sheets were characterized by low fatigue crack growth rate (0.28-2.85 mm/kcycle), while the extruded panels, being higher strength than the sheets, showed higher levels of FCGR. The sheets have an advantage over 1163T alloy (2524-type) alclad sheets (FCGR = 3.8 mm/kcycle at ΔK = 31 MPa√m) [3].

Results of low cycle fatigue tests of 1441 alloy sheets and extruded panels are given in Table 4.

Table 4: Low-cycle fatigue of 1441 Al-Li sheets and extruded panels.

Product	Orientation	Durability, kcycles
Sheet	Longitudinal	234
	Transverse	260
Extruded panel	Longitudinal	248
	Transverse	352

The average fatigue durability of 1441 alloy sheets exceeded that of 1163T (T3-type) alloy alclad sheets of 2-4 mm in thickness (110-120 kcycle; f = 3 Hz) [3].

4. Conclusions

The wide-scale tests of various mechanical properties undertaken corroborate the efficiency of application of corrosion-resistant alloy 1441 in airframe structures in preference to 1163 alloy. The 1441 alloy ensures the required level of service life and a considerable reduction in structural weight.

References

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