THE STRUCTURE AND PROPERTIES OF СИАЛ (GLASS / EPOXY - ALUMINIUM) LAMINATES.

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ABSTRACT The basic structural properties of hybrid laminates of grades СИАЛ[1]-2, 3 (GLARE-3, 4 – type) consisted of alternating thin aluminium sheets and adhesive prepreg layers with cross-ply high-strength glass fibres are presented, as compared to those of monolithic sheets. Such composites are intended for use in biaxially loaded sheet components. Their fracture behaviour at low cycle fatigue loading and also moisture ingress resistance of interlayers are described.
Keywords: *СИАЛ(GLARE) laminate, glass, aluminium alloy, adhesive, property.*

INTRODUCTION

СИАЛ (GLARE-type) are a new family of structural hybrid laminates, which are perspective as a replacement of monolithic aluminium sheets in primary elements of an airframe.

The appearance of Fibre Aluminium Laminates were as a logical step of development the idea, technology and experience in the field of wide application of adhesive bonded alumunium laminated joints and structures, having increased surviveability and reliability [1].

СИАЛ consist of alternating thin alumunium sheets from the main structural alloys (Д16ч – 2124-type; 1163 – 2324-type; В95оч – 7475-type; Li-bearing a.o) and prepreg interlayers "glass fibre / epoxy" [2]. As compared to traditional aluminium alloy solid sheets, which are used at present in aircrafts, the aforementioned materials differ by high fatigue and fracture resistance, improved mechanical properties, better impact–fire–resistance and lower density.

As compared to Organic Fibre-Aluminium Laminates of the first generation АЛОР (ARALL-type) [3], СИАЛ show superior advantages in tensile static strength, compression properties, moisture sorption resistance a.o. Moreover, glass reinforced materials are cheaper and more available.

A number, a thickness, a ratio of layers, structure of glass fibre reinforced plastic layer, composition and surface state of aluminium sheets depend on Laminate purpose.

In the present article the results of tests of СИАЛ-2 variant with cross-ply reinforcement (GLARE-4-type) are specified, the fibres of which are oriented in two directions in the ratio of 70/30 %. It is intended for application in biaxially loaded components, such as fuselage skins.

EXPERIMENTAL PROCEDURE

Typical structures of Laminates investigated are represented in table 1. On general clad sheets of 0,3 mm thickness from Д16чТ, 1163Т alloys were used, which are the main prefered fuselage skin material. Thin sheets were chromic acid anodized and then were primed. Fibres of high-strength, high-modulus glasses (table 2) [4] were used as reinforced materials. Prepregs were used on the basis of high-strength thermoset adhesive resins VK-51-type [1], which ensure good adhesive properties on interface metal - polymer, polymer – fibre and high cohesion strength of polymer. Prepregs were manufactured by melting technology. Curing was carried out in a autoclave (or in a press) in general by conventional bonded technology. Cross-ply reinforced СИАЛ-2 and СИАЛ-3 were not post-stretched.

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[1] СИАЛ is the abbriviation from Russian words: **Стекло** – Glass, **И** – and, **АЛюминий** – Aluminium.

Table 1. Typical structure.

СИАЛ		Al sheet		Typical structure	
Thickness, mm	Lay-up	Thickness, mm	Alloy	Thickness, mm	Composition
0,8-2,0	3/2, 2/1	0,25-0,5	Д16чТ, 1163Т, В95очТ2	0,3-0,5	High-strength, high-modulus fibres + high-strength adhesive

Table 2. The Properties of Fibres

Characteristic	Glass grade	
	ВМП	ВМД
Density, g/sm^3	2,58	2,55
UTS, MPa	5000	4500
Elastic modulus,GPa	95	92
Coefficient of temperature expansion 10^7 (1/°C), 0-350°C	34,9	37,0

BASIC PROPERTIES

Obtaining or lowing down properties anisotropie of necessary value in accordance with service conditions for a structure or a part, is controlled with cross-ply reinforcement of plastic layers (table 3). For СИАЛ-2 these layers contain ~70 % glass-fibres in one direction and ~30 % - in perpendicular direction, that meets the requirements of biaxial loading of aircraft fuselage skins.

As compared to solid sheets from improved high-purity "duralumin" alloy 1163 (<0,15% Fe, <0,1% Si) in natural aged temper T, СИАЛ-2 differs by high crack-resistance (table 4): very low crack propagation rate, better fracture toughness (K_c^{ap}, $A_{c.f.}$) and by high strength as well as comparable properties under compression.

At standard low cycle fatigue tests of specimens with open hole (d_{hole} = 45 mm, width 30–35 mm, length = 200-220 mm) [5], СИАЛ exceeds 1163 sheets by total life (N). In thin aluminium sheets, being constituent of СИАЛ, fatigue crack initiation may appear earlier (N_0) (Fig. 1), than in monolithic ones (for which the prevailed fraction of fatigue life consists of the crack initiation period). However in aluminium СИАЛ sheets the crack grows very slow and may come to a standstill at the length of few (1 – 5) mm (ref. to Fig.1).

Fractographic studies show that in composites with increased durability fatigue onset zone occurs at the edges of the hole (Fig. 2 a), but in composites with lower durability – at a certain distance (0,1 – 0,4 mm) from the hole wall at the side of an interface "metal-polymer layer" (Fig. 2 b) [2,7].

However, a riveting is the basic process for joining the skin aluminium alloy sheet elements in structures in real life. And namely in the riveted joints the greatest advantages are achieved for this type of laminated composites, especially СИАЛ (GLARE), as far as low cycle fatigue behaviour is concerned (not only by the crack growth period, but also the crack initiation period).

As the fatigue test (σ_{max}= 80-100 MPa. f= 3-5 Hz) of a longitudinal four-raw riveted lap joint

Table 3. Typical mechanical properties of СИАЛ.

Fibre orientation (vol. %)	Direction	UTS, MPa	UYS, MPa	Modulus E, MPa	Ultimate Strain ε, %
		СИАЛ-2 (GLARE-4 type) -			
0 / 90 / 0 (70 / 30)	L	800-900	280-320	55 000-58 000	3,5-5,0
	LT	500-600	220-250	47 000-50 000	3,5-5,0
		СИАЛ-3 (GLARE-3 type) -			
0 / 90 (50 / 50)	L	650-700	250-300	55 000-58 000	4-5
	LT	640-690	230-280	55 000-58 000	4-5
		СИАЛ-1H (GLARE-2 type) -			
0 (100 / 0)	L	1100-1200	300-350 (450-500)[x]	60 000-65 000	4-5
	LT	250-300	200-250	45 000-50 000	11-13

* - after stretching;

Table 4. Damage tolerant and fatigue properties*.

Characteristic	СИАЛ-2	1163T
UTS, MPa	850	450
CYS, MPa	320	290
dl/dN, µm/cycle (ΔK=31 MPa$\sqrt{m}$)	<0.1	1.9
K_c^{ap}, MPa$\sqrt{m}$(panel 140x450 mm):	100	60
$A_{c.f.}$**, G/sm^2	23	12
Low Cycle Fatigue N, kcycles (σ_{max}=156 MPa, K_t=2.6, f=3 Hz)	>350***	120

*) L- direction;
**) Notched and fatigue cracked impact test specimen;
***) Fracture of AL sheets.

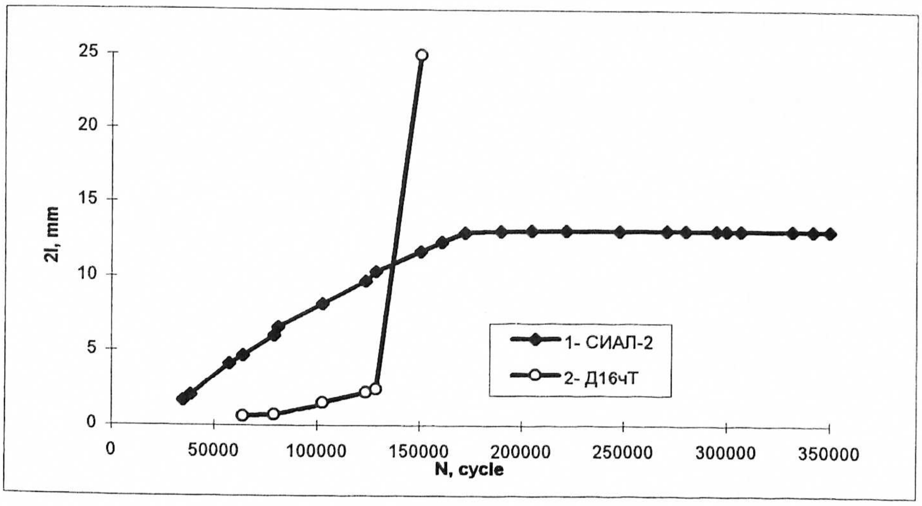

Fig. 1. Crack growth in surface aluminium layers of СИАЛ-2 Laminate (3/2; cross 70:30) and in monolitic aluminium Д16чАТ sheets at low fatigue tests (σ = 158 MPa; f = 5 Hz, K_t = 2,6)

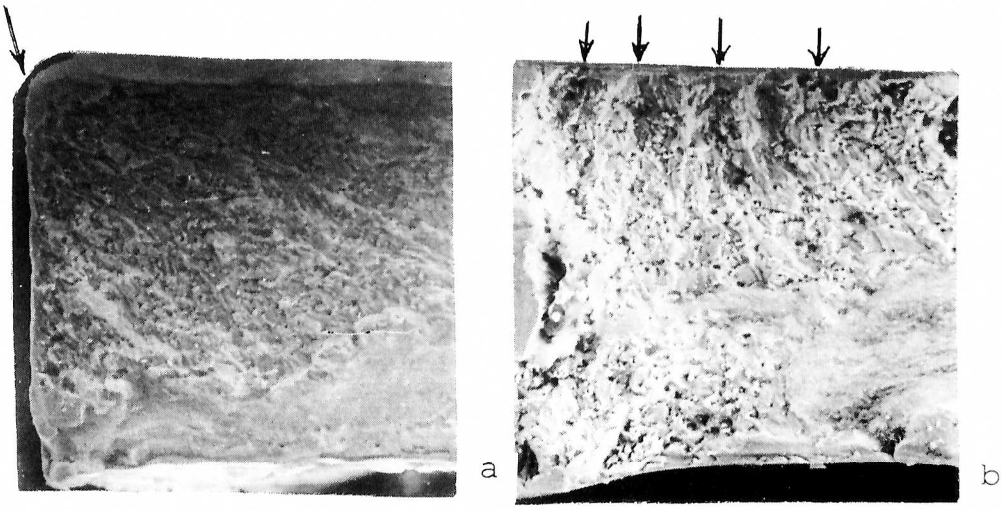

Fig. 2. SEM micrographs showing nucleation of fatigue fracture: the edge of hole (a), some distance from hole wall (b)

One of the important Laminate advantages (opposite to purely reinforced plastic as against) is the fact they maintain a technological efficiency mainly close to aluminium alloy in aged tempers (T, T1, T3, T6 for duralumin - types) during their processing into parts and elements due to aluminium sheet availability on the outer surface and their larger volume fraction (>60%). But there are some differences associated with the lesser ductility, stiffness, compressive properties of the reinforced plastic interlayers and presence of interfaces bet ween constituents with laminated - fibrous structure.

The traditional riveting process is accompanied by the compressive and tangential forces in the zone under the snap rivet head and tangential deformation, generated in case of the rivet bar thickening. It was established that a thickening can achieve 10 percent under acceptable riveting conditiins of unidirectional СИАЛ-1Н. The comparison of the structures and microsections measuring has shown, that the deformation can be observed only in two composite layers, adjacent to the snap head. In this case the outer aluminium sheet is practically not thinned, but only bented (fig. 3). The glass fibre reinforced polymer layer adjacent to it is thinned near the rivet bar by 7-20%.

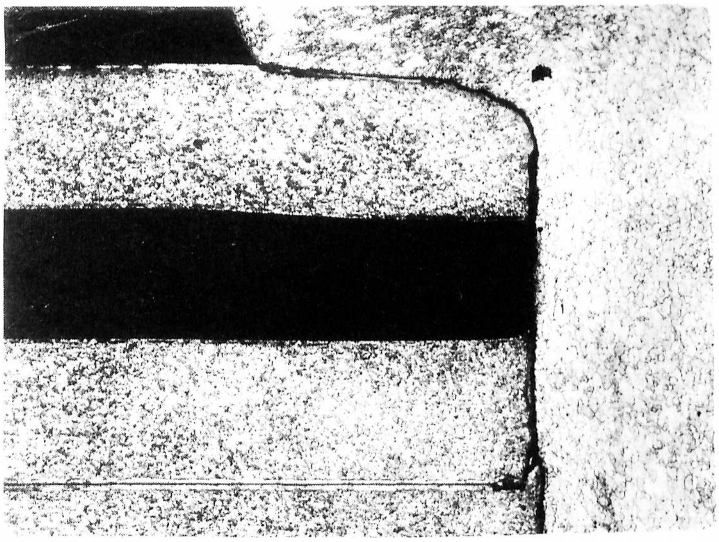

Fig. 3. The microstructure of unidirectional СИАЛ-1Н joint cross-section from the side of rived head snap. 50x

Taking into consideration a great number of interfaces between constituents of Laminates (which first of all get revealed in rieted holes and on the edges), it is very important to carry out corrosion tests of these composites. Long exposure under corrosion environments, simulated tropical and sea conditions, show СИАЛ good moisture resistance. Anticorrosive cladding, anodized and primed coatings on aluminium sheets contribute to these properties of СИАЛ.

However, there is on opportinuty of introducino moisture into glass/epoxy layers. To evaluate moisture ingress comparative accelerated tests were carried out for СИАЛ (GRARE- type) and АЛОР Д16/41 (ARALL-type) [3] specimens of different demensions with unprotected edges under rigid conditions: temperature ~60°C, relative humidity ~100%.

Moisture content, determined by specimens weighting, was calculated from formula:

$$W_t = \frac{m_t - m_o}{m_o}, \quad m = m_c - m_{Al}$$

where: m_o , m_t - plastic layer weight in initial state and after exposure "t", correspondingly; m_c , m_{AL} - СИАЛ specimen and Al sheet weight, respectively.

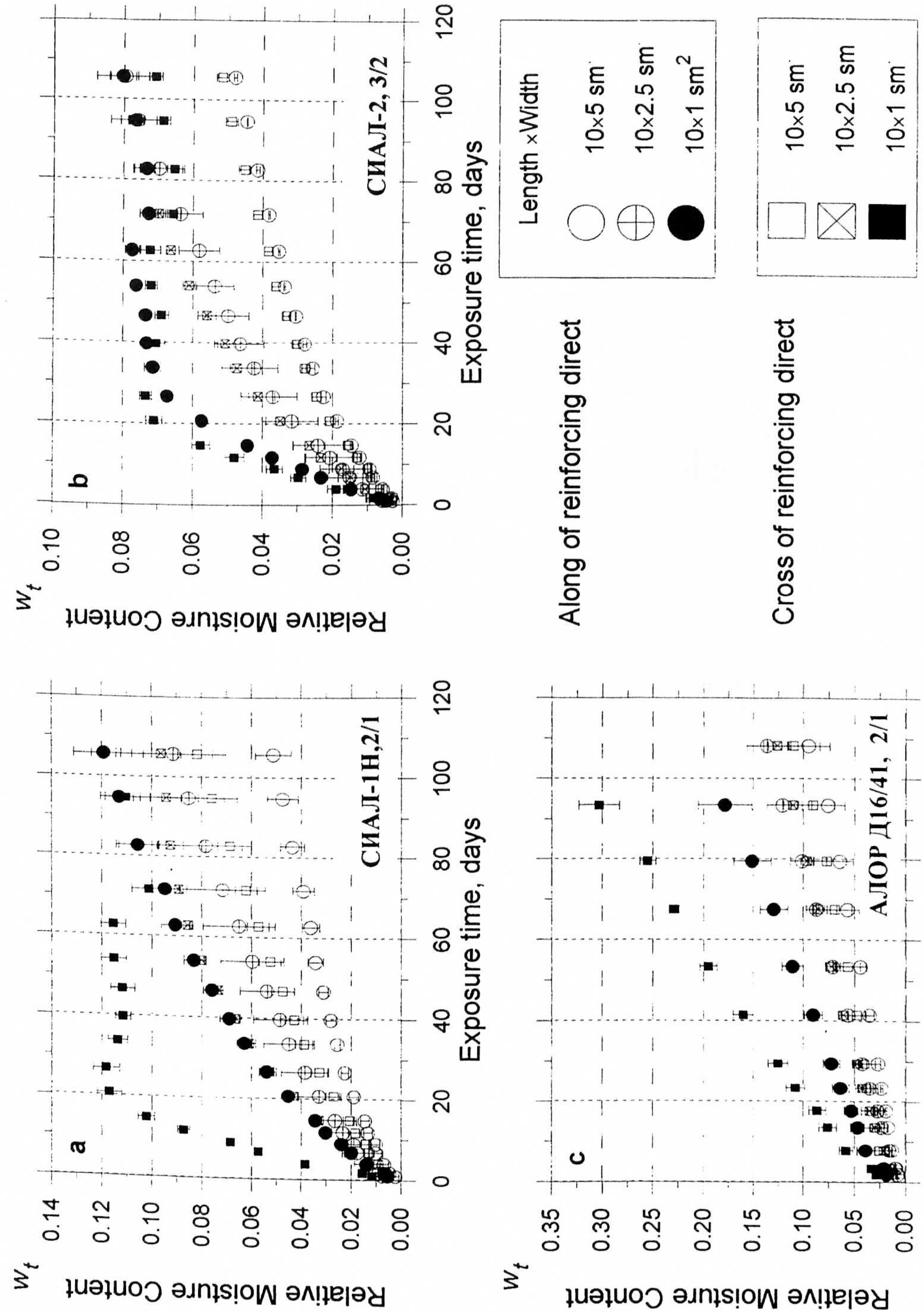

Fig.4. The kinetic of water, sorption in glass – (a,b) and organic (c) fiber reinforced plastic.

A comparative analysis of two types Laminates soption characteristics confirmed better СИАЛ resistance to moisture enviroument (Fig. 4). АЛОР specimens were delaminated fully in 50 days, but no visible damages of СИАЛ specimens were discovered after 120 days.

Anisotropy of sorption Laminates properties was observed: moisture ingress is higher in transversal direction. Difference in the rate of moisture content growth for specimens of sorption different shape is explained by presence of edge damages, appeared under machining.

However the technological conditions of aluminium sheet parts production can't be automatically transffered to the production of Laminate parts and require the engineering knowledge and technological solutions as well as new culture for design.

CONCLUSIONS. Wide variety of the Laminates gives on opportunity for a designer to choose a proper material for his aimes СИАЛ-2 and СИАЛ-3 with cross-ply glass orientation are designated at first for fatique critical primary skins of fuselage, leading - edge slats etc. They are suitable for carring out repair works as crack stoppers. Combination of high damage tolerance and a specific strength, good fatique and corrosion performances make it possible to consider these materials as a advanced one for aircrafts of future generations.

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