The structure and properties of laminated aluminum-glass reinforced plastics

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Abstract. The current state of the problem of the use in aviation of new laminated aluminum glass-reinforced plastics (Glare) is given in this review. It is shown that Glares are characterized by low density (2.4 g / cm³), high strength (> 600 MPa), but at the same time they are inferior to aluminum alloys by the elastic modulus (<60 GPa). Methods for evaluating Glares service characteristics are considered, it is indicated that replacing traditional aluminum alloys in Glares with lithium alloys that have unique elastic properties can significantly improve their service characteristics.

1. Introduction

Significant progress in the use of new materials in aviation is associated with composite materials, such as layered aluminum-glass-plastics-Glare, which are distinguished from monolithic sheets from aluminum alloys by a density reduced by 10-15% (2.4 g/cm³), high strength (σ> 600 MPa), fire resistance [1-3].

The use of Glares in the fuselage skin of the A-380 airbus led to a weight saving of more than 500 kg. At the same time, Glares are inferior to aluminum alloys in such an important modulus as elastic modulus [4]. VIAM [5, 6] proposed a new class of Glares based on aluminum-lithium alloys, which made it possible to increase the elastic modulus by 8–10% and decrease the density by 5–7%. In this paper, the structure and properties of Glares are considered.

2. Results and discussion

Figure 1 shows the appearance and "construction" of Glare, which usually consists of three layers of aluminum alloy, between which are packages of epoxy prepreg layers reinforced with fiberglass, which can be located in each of the two layers of both packages in one, shared direction (0°/0°) or in the fractional and transverse (0°/90°) directions (table 1). Characteristics of Glares and the corresponding preferential properties are also given in table. 1. Sophisticated complex manufacturing technology of Glares requires various testing and control methods for product quality control. A significant number of studies of composite materials, including Glares, are devoted to the determination of their mechanical and elastic characteristics, including in conditions of multi axial stress states.

This is due to the strong anisotropy of Glares, the high sensitivity of their properties to technology parameters and the presence of complex correlations of their mechanical properties with structural and geometric parameters. One of the important areas of research is also the development of non-destructive methods of quality control of Glares. Without the creation of such methods, their use in critical aircraft components would be impossible, since in most cases the material itself and the part are made of it at the same time and a separate material test cannot be carried out.

One of the most important advantages of Glares in comparison with metallic materials is its high resistance to fatigue crack growth. For this reason, much attention is paid to the modeling of this process [7-9]. In [7], analytical approximations are proposed for predicting the fatigue crack growth rate based on empirical relations of the Paris type, in which the effective stress intensity factor (SIF) is adjusted based
on the bridging effect. It is implied that the decrease in fatigue crack growth rate in Glares occurs due to a zigzag change in the trajectory of the crack, leading to its branching and a decrease in the SIF by $K$.

Quantitatively, this effect is determined by the dimensionless coefficient $\beta$ equal to the ratio of the $K_{br}$ value to the SIN value that a crack would have in the absence of overlap ($K_0$). Figure 2 shows the stress values in each layer of the Glare 4A-3/2.

![Figure 1. Type of Glares](image)

It is seen that tensile stresses act in the metal layer, and curing stresses in the prepreg are absent in the fractional direction and compressive in the transverse direction. As a result, the crack under cyclic loading is revealed by the applied load in the metal layer and is closed by the overlapping stresses in the prepreg. In [9], a critical analysis of all existing forecasting models of fatigue crack growth rate Glares was carried out, the main drawback of which the author considers the underestimation of such an important factor as the stratification effect. The author believes that the consistency of predictive models with experiment is largely due to an insufficient amount of experimental data. When developing his own model, the author was based on two fundamental positions. Firstly, on a detailed study and description of real fracture mechanisms in Glares, and secondly, on the development of such a model of crack growth and stratification in Glares under fatigue loading, which would exactly correspond to the fracture mechanisms mentioned above. When developing his model, the author adhered to the following important criteria:

- analytical relationships should be based on physical mechanisms without the use of adjustable parameters;
- the model must accurately predict the growth rate of the fatigue crack compared with experimental results in a fairly wide range of experimental parameters;
- the results should not depend on the initial parameters, such as the length of the crack and the shape of the bundle.

As a result, the author proposed a model that allows one to take into account the stratification effect when calculating the energy balance, which is in good agreement with the experimental results. For technologists in his approach, it is important that the author introduces a parameter into his model, which in practice has shown its importance for the performance of Glares, namely the parameters of the interface between the metal component and the prepreg. From this point of view, the model proposed in [7] makes it possible in the future to search for quantitative correlations between technological parameters characterizing the adhesion characteristics of the interface with service properties, of which the fatigue crack growth rate parameter is one of the most important for ensuring the reliability of Glares in aircraft.
Table 1. Standard assortment of Glares and advantageous properties.

| Glare grade | Sub | Metal sheet thickness [mm] and alloy | Prepregorientation*in each firbelayer) | Main beneficial characteristics |
|-------------|-----|------------------------------------|--------------------------------------|---------------------------------|
| Glare 1     | -   | 0.3-0.4 7475-T761                 | 0/0                                  | Fatigue, strength, ultimate strength |
| Glare 2     | Glare 2A | 0.2-0.5 2024-T3                 | 0/0                                  | Fatigue, strength               |
|              | Glare 2B | 0.2-0.5 2024-T3                 | 0/90/0                                | Fatigue, strength               |
| Glare 3     | Glare 4A | 0.2-0.5 2024-T3                 | 0/90/0/90                            | Fatigue, strength, ultimate strength |
|              | Glare 4B | 0.2-0.5 2024-T3                 | 90/0/90                              | Fatigue, strength               |
| Glare 5     | -   | 0.2-0.5 2024-T3                 | 0/90/90                              | Impact                           |
| Glare 6     | Glare 6A | 0.2-0.5 2024-T3                 | +45/-45                              | Shear, off-axis properties      |
|              | Glare 6B | 0.2-0.5 2024-T3                 | -45/+45                              | Shear, off-axis properties      |

*All aluminium rolling directions in standard laminates are in the same orientation; the rolling direction is defined as 0°, the transverse rolling direction is defined as 90°.

The number of orientations in this column is equal to the number of prepreg layers (each nominally 0.133 mm thick) in each fibre layer.

Interesting results were obtained in [10] when studying the elastic properties of composites. The experimental values of the elastic characteristics for GF/E and Glares turned out to be close to the calculated values calculated for the GF/E composite based on micromechanical modeling (E_{GF/E}), and for Glares based on the additivity rule (Table 2):

\[
E_{AI} = E_{Al} \cdot V_{Al} + E_{GF/E} (1-V_{Al})
\]

Figure 2. The stress levels in Al layer and curing stress in each layer for Glare4A-3/2 laminate under cyclic loading at RT with a frequency of 10 Hz. The maximum applied stress was 160 MPa with a stress ratio of 0.1.
4. Lithium alloys, which have unique elastic properties.

Therefore, the most effective way to increase the elastic modulus of Glare is to increase the elastic modulus of the metal component. An effective way to increase the elastic moduli is to form intermetallic phases in the alloy particles, which usually have higher elastic properties compared to the matrix. For an Al-Li intermetallic with L1_2 lattice, the anisotropy of the elastic moduli can be quite high, and since it is known that it has a pronounced texture (coinciding with the alpha-solid solution), Mg-Li system alloys can have a noticeable anisotropy of elastic properties in the sheet plane, which must be taken into account in the calculations and cutting the sheet, and the magnitude of the anisotropy is due to the type and intensity of the texture and the amount of intermetallic.

Table 2. Properties of Glare components.

| Properties | Al (2024-T3) | Prepreg(Glass fiber/Epoxy) |
|------------|--------------|---------------------------|
| E_x (GPa)  | 72.4         | 55.5                      |
| E_y (GPa)  | 72.4         | 9.5                       |
| E_3 (GPa)  | 27.6         | 5.55                      |
| ν_{xy}     | 0.33         | 0.3                       |
| ν_{yx}     | 0.33         | 0.0575                    |

Table 3. Elastic properties of Glare and epoxy fiber composite.

| Material     | Fraction content (%) | Parameters used in the FGM (a) program and the mixtures rules | Calculation (experiment) |
|--------------|----------------------|---------------------------------------------------------------|-------------------------|
|              |                      | E_x, GPa | E_y, GPa | G_{12} | ν_{12} | E_x, GPa | E_y, GPa | ν_{12} |
| Epoxy        | 40                   | 5        | 5        | 1.85   | 0.3   | -        | -        | -      |
| Glassfiber   | 60                   | 72.0     | 72.0     | 28.8   | 0.14  | -        | -        | -      |
| Aluminum 2024-T3 | 57          | 72.4     | 72       | 28.0   | 0.33  | -        | -        | -      |
| Gf/E         | 43                   | -        | -        | -      | -     | 30.6(27.4)| 30.6(27.4)| 0.38   |
| Glare        | 100                  | -        | -        | -      | -     | 54.8(57.3)| 54.8(57.3)| 0.25   |

(a) Fabric Geometry Model software

3. Conclusions
1. The article presents an overview of the state of the problem of using new laminated aluminum glass-reinforced plastics - Glare in aviation.
2. It has been shown that, along with the significant advantages of composites (with a density of 2.4 g/cm³, σ0 > 600 MPa, significantly higher crack resistance), they are inferior to monolithic aluminum alloys by the value of the elastic modulus.
3. It is shown that the elastic properties can be improved only due to the metal component of the composite, which can be achieved by replacing the traditional aluminum alloys in Glare with aluminum-lithium alloys, which have unique elastic properties.

4. References
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