Aluminum/glass fibre and aluminum/carbon fibre hybrid laminates

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Abstract: *The metal/fibre hybrid laminates consist of an alternation of 0.2 ÷ 0.5 mm metallic sheets (Aluminum or Titanium in Aeronautical Engineering) and pre-pregs made of unidirectional carbon or aramid or glass fibre or of the two-dimensional fabric of these materials, bonded by a polymer adhesive (epoxy, especially). Compared with the monolithic metal foils, the essential quality of these hybrid laminates is their superior resistance to fatigue, impact and crack propagation (existing or made by notches). The paper presents some results regarding hybrid laminates aluminium-carbon fibre and aluminum-glass fibre achieved in the CEEX project X1C05 (2005).*

Key Words: fibre - metal laminate (FML), carbon fibre reinforced plastics (CFRP), glass fibre reinforced plastics (GFRP).

1. GENERAL REMARKS

Hybrid materials - a new concept of materials - consist mainly of an alternation of metal alloy and pre-preg unidirectional fibres or FF, GF and aramid fabrics sheets.

This metal/fibre hybrid laminates offer remarkable mechanical and fatigue properties as well as fracture strength and a relatively low crack propagation rate.

The Original patent of The University of Delft (from the 80-s) named Fibre Metal Laminates (FML): ARALL (Aramide – Aluminum – Laminates) was developed afterwards as composites made of a mixture of Aluminium-Carbon fibre, and Titanim-Carbon fibre:

- Laminates with a forming temperature of 120^0 C as pre-pegs for cold aerospace structures.
- Exposy system type-laminates with a forming temperature of 180^0 C for high temperature
- Thermoplastic adhesives laminated with for use at high temperatures up to 2500 C.

The GLARE type hybrid laminates were utilized for the space programme Hermes.

Some well known examples are: ARAL GLARE and FML with aramide and glass fibres respectivelly which are embedded in the aircraft epoxy systems:

- ARALL was developed for the lower wing skin panels of the Fokker 27 aircraft and for the Boeing C 17Cargo doors.
  - GLARE is currently used as coating material for the Airbus A380 fuselage to the wing leading edge

The concept has been applied not only to aluminum-aramide and glass fibres structures but also to other constituents.

Table 1 gives a selection of some laminates.

Table 1. Selection of FML Types and FML Constituents Applied and Investigated in the Past Decades

FML Type	Metal Constituents	Fibre/Polymer Constituents
Arall	Aluminium 7075-T6	Aramid/BSL-312-UL Aramid/AFI63-2
Glare	Aluminium 2024-T3 Aluminium 7475-T761	S2-Glass/FM94 S2-Glass/FM906
Carall	Aluminium 2024-T3	T300-Carbon/epoxy
TiGr	ß Titanium Ti-15-3	IM7 Carbon/Polyimide
	AISI301 Stainless Steel	Strafil C-EP 1-150/epoxy

The continuous increase in requests for international and long distance transport resulted in the necessity of civilian transport supersonic aircraft, which are relatively expensive.

Therefore this includes minimizing the mass of the aircraft while increasing the aircraft life to recover the investment in a long period of time. For example the fuselage, wings and other parts of the airplane should be light but also have several properties such of high strength to weight ratio, lasting endurance strength and high thermo-mechanical endurance to stand high temperatures during supersonic flight.

The aircraft fuselage, external panels, wings and control surfaces made of metal such as titanium alloys don’t meet all the performance criteria for an advanced supersonic civilian aircraf.

Moreover, titanium panels sizes are limited due to their physical properties such as a large aircraft require more joints of the panels and thus weight gain. Titanium alloys have a relatively high density, being relatively expensive.

Titanium alloys also have low fatigue resistance and high rates of crack progression.

As an alternative, the aircraft fuselage and exterior panels could be made from polymeric composites (heat resisting or thermoplastic matrix)with embedded CF or GF as stiffening fibres).

The performance of these composites can change as a result of repeated exposure to relatively high temperatures during the supersonic flight (~175ºC).

Polymer composites are also susceptible to undetectable mechanical damage that can compromise their structural integrity. Also, polymeric composites are susceptible to damage caused by lightning and therefore require additional structure conductive.

Hybrid laminates, including layers of titanium alloy alternating with layers of a polymeric/FC composite that form the skin (e.g. fuselage, wings, stabilizer) have a high strength – to – weight ratio, a modulus, high fatigue resistance, and remarkable endurance properties.

Moreover, hybrid laminates have a great strength and resistance to crack propagation even for the bolt joints or other stiffening elements.

The polymeric composites layers in the laminates should be protected from thermal oxidation, water ingress and damage that could be caused by exposure to fuel and other solvents.

2. ALUMINIUM/CARBON FIBRE AND ALUMINIUM/GLASS FIBRE HYBRID LAMINATES MANUFACTURING

- Aluminium/carbon fibre laminates made of three aluminum foils of 150x150x0.35 mm and two foils of carbon fibre fabric impregnated with epoxy resin, finally resulting in plates of 150x150x1.55 mm;
- Aluminum/glass fibre laminates (150x150x1.5 mm) made of 3 aluminum foils and 2 exposy resin impregnated glass foils which results in plates of 150x150x1.55 mm;

The composites manufacture required the acquisition of the following materials:

- T1 status aluminum foil of 0.35 mm thickness, (imported product);
- E22 glass fibre fabric, made by FIROS-Bucharest ;
- imported CARP193 carbon fibre fabric, with the following characteristics:
    - K Cable (3000 filaments);
    - 100% carbon content;
    - Weight 193 g/m^2;
    - thickness 0.23 mm;
    - Fineness - 1.1 dtex;
- Impregnating material, used as an adhesive:
    - modified epoxy resin P401;
    - Teta1-hardener (trietilentetraamina);
    - Resin-hardener-ratio 100/11.

In another stage Epolam 2001-resin and hardener were used.

The obtaining technology consisted of three successive stages:

- Sonic degreasing of aluminum foils in acetone bath;
- Sandblast cleaning of the aluminum foil active surfaces to increase adhesion of resin-metal;
- Dipping of carbon or glass fibre fabric;
- In-mold-mounting;
- Cold –compressing at at 3.5 daN/m^2 for 24 hours;
- 7 days in air- ageing.

3. MECHANICAL TESTING OF HYBRID COMPOSITES SPECIMENS

The valuation of mechanical properties consisted in three distinct stages:

- Bending Test (three point method)
- Tensile test
- Tests for the notch effect

All tests were performed with an Instron 4301 installation, presented in earlier works, under the regulations or standards specified for each type of test.

The paper contains the test report comprising the results of the experiments.

3.1. Bending strength test

The bending strength testing through the “three points” method was performed on samples of hybrid composite plates using the Instron 4301 installation with an original system of support and stress applying.

The tests were performed according to the ISO-1425 and ASTM-790M-93 standard regulations.

The rectangular 25x15 mm samples have the following thickness:
– 0.35 mm for aluminium foil
– 1.55 mm for composites made of 3 aluminium foils and 2 carbon fibre fabric foils
– 1.55 mm for composites made of 3 aluminium foils and 2 glass fibre fabric foils
– 1.54 mm for laminate made of 4 aluminum foils

Synthetic results are presented in Table 2 where:
1. Aluminum foil monolith;
2. Al+ 2 CF - Hybrid laminate made of 3 aluminum foils and 2 carbon fibre fabric foils;
3. Al+ 2 GF- Hybrid laminate made of 3 aluminum foils and 2 glass fibre fabric foils;
4. Al - Laminate made of 4 aluminum foils sticked together.

Table 2 presents the results of the bending of composite samples

Table 2.Results of the bending of composite samples

No.	Material	Strength MPa	Strength MPa
		ResinP401	Epolam Resin
1.	Al	178	178
2.	3 Al + 2 FC	325	329
3.	3 Al + 2 FS	188	217
4.	4 Al	145	145

Consecutive observations of the data in the table above can be summarized as follows:

- Aluminum-carbon fibre hybrid laminates had a superior resistance compared to laminates of aluminum foil or to monolithic aluminum foil (385 MPa compared to 178 for monolith foil);
- Four - aluminum foil laminates had a lower resistance as compared to monolith foil (145.9 MPa against 178 MPa);
- Aluminum-glass fibre hybrid laminates were superior as compared to monolithic aluminum, but the differences were not significant(188 MPa versus 178 MPa);
- Hybrid laminates corresponding to the second stage (Epolam 2001 resin) reveal higher values, especially in case of glass fibre (from -217 MPa to 188 MPa when using P401 resin)

It should be noted that with hybrid laminates the failure was made by delamination, a phenomenon that has not been present with four foils specimen.

This remark is illustrated by pictures a-c in Figure 1, where positions a and b are for aluminum-fibreglass laminates, c for aluminum-carbon fibre, and d for the four - foil laminate.

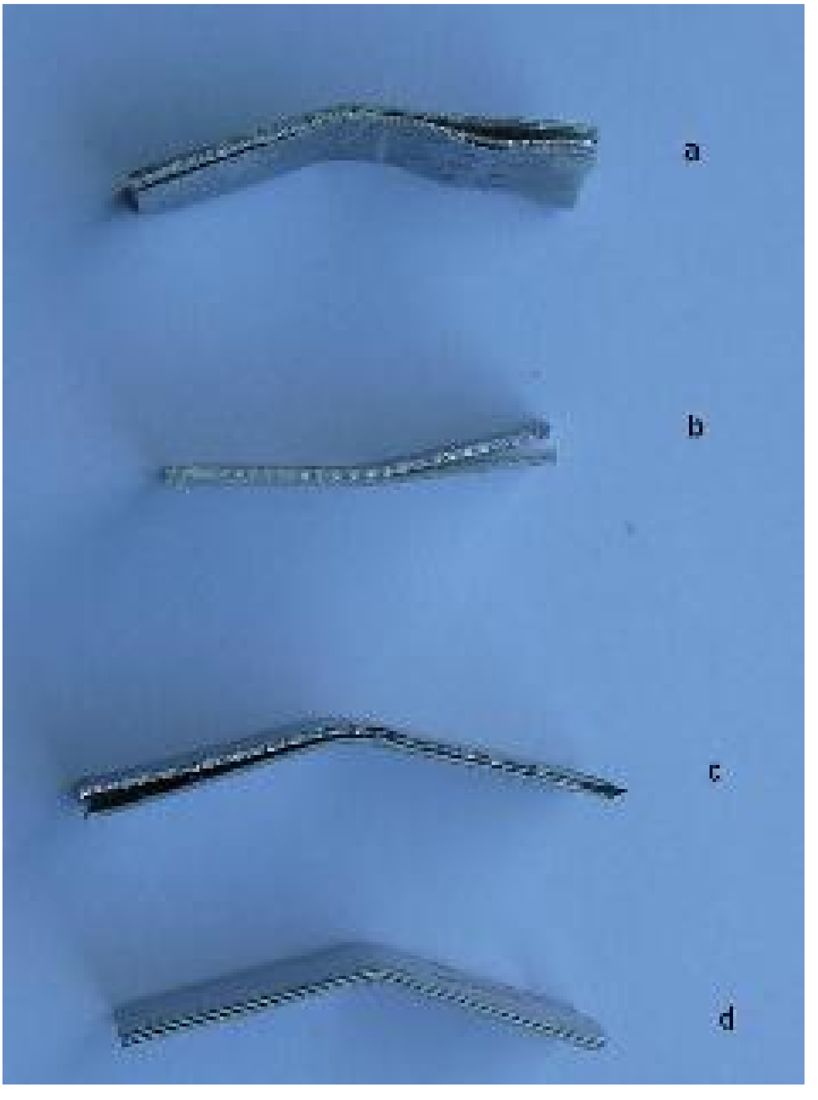

Fig. 1. Images of the cross-section of hybrid composites
- **a, b** - Aluminum-glass fibre hybrid laminates
- **c** - Carbon fibre/ aluminum hybrid composite laminates
- **d** - Laminate made of 4 aluminum foils

3.2. Tensile strength test

The tensile strength tests were performed according to the ISO-527 or ASTM 3039-93 standard regulations.

The test results are given in table 3, where

- Al – aluminum foil of 0.35 mm
- FC – Carp 193impregnated carbon fabric;
- FS E-0.22 impregnated glass fibre
- 2 Al + 2 FC – Hybrid laminate made of 2 aluminum foils and 2 carbon fibre fabric foils;

- 2 Al + 1 FC – Hybrid laminate made of 2 aluminum foils and a carbon fibre fabric foil;
- 2 Al+ 1 FS – Hybrid laminate made of 2 aluminum foils and a glass fibre fabric foil;

Table 3. Composite samples tensile strength

No	Material	Tensile strength MPa	Tensile strength MPa
		P401 Resin	Epolam Resin
1.	Al	135	135
2.	FC	400	400
3.	FS	200	200
4.	2Al + 2 FC	250	250
5.	2 Al + 1 FC	220	230
6.	2 Al + 1 FS	145	170

In this case also one can notice the superior resistance of the aluminum-carbon fibre laminate as compared to monolithic aluminum or fibreglass aluminum composite (2200 kg / cm 2, compared to 135 MPa for monolithic aluminum and 145 MPa for aluminum-glass fibre laminate respectively).

No tensile tests have been performed for "standard" hybrid laminates of 3 aluminum foil + 2 foils of carbon fibre as the force required would exceed the INSTRON4701 (KN 5000) installation limits.

The higher strength values of fibreglass and resin Epolam laminates are to be noted. In other cases, the strength of the two kinds of P401 and Epolam resin laminated were actually identical.

3.3. Notch effect testing into the laminated composites

The test was performed according to ISO 14125 and ASTM-93

V notches of 1 mm in deep were made on similar samples to those utilized for the tensile mechanical testing which were mounted on the Instron 4301 installation devices to be tested.

The results are shown in table 4, where:

1. Al-aluminium foil;
2. Al-(notched) aluminum foil with 1 mm V notch;
3. 2 Al + 1 FC – laminated composite of 2 Al foils and 1 foil of carbon fibre;
4. 2 Al + 1 FC – (notched) - No 3 composite with V shaped notches of 1 mm on both sides of the samples;
5. 2 Al + 1 FS – laminated composite of 2 Al foils and 1 glass fibre foil;
6. 2 Al + 1 FS – (notched) - No 5 composite with lateral notches;

Notch effect into metal –fibre hybrid composites Table 4.

Crt No	Material	Tensile strength MPa	Tensile strength MPa
		P401 Resin	Resin Epolam
1.	Al	135	135
2.	Al, notched	100-95	100-95
3.	2 Al + 1 FC	220	225
4.	2 Al + 1 FC, notched	210-215	215
5.	2 Al + 1 FS	145	170
6.	2 Al + 1 FS, notched	1400	161,5

The main observation is that with aluminum monolith foil the notch effect is obvious (reducing the specific resistance from 135 MPa); in case of hybrid composites the effect is almost imperceptible (reducing strength from 220 MPa to 200 MPa for aluminium-carbon fibre hybrid laminates and from 144 MPa to 140 MPa when aluminium - fibreglass laminates). It is worth noting the superior behavior of the laminate with fibreglass and Epolam resin as copared to P401 resin (170 MPa against 145 MPa).

4. CONCLUSIONS

This paper presents comparative data on bending and tensile strength between hybrid laminates, monolithic aluminum foil and laminates with four aluminum foil, having the same thickness as the hybrid laminates.

It has been revealed the higher behavior of carbon fibre aluminum laminates compared to aluminum-fibreglass laminates in the following hierarchy:

- Hybrid laminate 3 Al + 2 CF - σ = 325 MPa;
- Hybrid laminate 3 Al+ 2 GF - σ = 188 MPa;
- Laminate made of 4 aluminium foils - σ = 145 MPa.
- Tensile testing revealed the same hierarchy.

The tests aiming to assess the effect of notch on mechanical resistance showed that the hybrid laminates have superior resistance compared with the monolith aluminum foils. It should be noted that the superiority of mechanical behavior of hybrid composites compared to monolithic aluminum consisted in the reduction of the notch effect and the reduction of crack propagation.

The paper has been completed with mechanical test achieved at UPB to evaluate the composite materials regarding their fatigue, impact and concentrate effort; these tests will be presented in a future paper.

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