ELABORATION AND EVALUATION OF CARBON FIBER ALUMINIUM COMPOSITES FOR AEROSPACE APPLICATIONS

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ABSTRACT

Aluminium matrix composites plates and feasibility parts were elaborated using a gas pressure infiltration casting process and preforms of carbon fibers. An ultra high modulus graphite fiber, in order to avoid a strong chemical reaction between reinforcement and liquid metal, and casting alloys were chosen.

Room temperature and high temperature (up to 350°C) tensile tests were performed on unidirectionally reinforced plates in order to determine the Young's modulus and the ultimate tensile strength of the composite materials. The fatigue behaviour of the composite materials was evaluated using R=0.1 fatigue tests.

Following the study of materials properties, two feasibility parts representing aerospace applications were elaborated and tested : a stiffened panel and an attach fitting component.

Keywords: *Metal Matrix Composites, Aluminium alloys, Carbon fibers, Infiltration process*

1. INTRODUCTION

Metal Matrix Composites (MMCs) are one of the new concepts which are thought to bring a major step forward in AEROSPATIALE applications. Strong interest has driven the development of processing of continuous carbon fiber reinforced aluminium (C/Al) either by foil-fiber-foil, or tape casting, or Physical Vapor Deposition coated fiber pressing. These approaches tend to be expensive. Consolidation and the required tooling for component production add costs far above the material manufacturing price. Therefore casting techniques that could produce near net shape reinforced components were investigated.

2. SELECTION OF THE ELABORATION PROCESS

The selected process : **Gas Pressure Infiltration Casting** is described on figure 1. It is a form of liquid infiltration which utilizes pressurized gas to force liquid metal into a preform of reinforcement material.

After the mold is loaded with a carbon fiber preform and clamped together, and a block of metal is placed in the crucible, the mold and the crucible are heated under a primary vacuum. In order to limit the formation of aluminium carbide when using carbon fibers and aluminium alloys, the metal is heated in a separate crucible located above the mold. The melt and the mold can be taken to different temperatures. After the mold and the melt have reached the desired temperatures, a plug is lifted out of the bottom of the crucible allowing metal to flow into the mold, isolating a vacuum inside the preform. The vessel is then pressurized using an inert gas until the mold is filled and the preform is infiltrated. Then a chilling system is used to cause the component to solidify towards the melt such as the shrinkage is contained in the melt reservoir. Pressure is held in the vessel until solidification is complete. After solidification, the mold can be separated and the parts removed.

Due to poor wettability of carbon fibers by liquid aluminium, each fiber-matrix couple required a specific set of processing parameters. The most important processing parameters are :

infiltration pressure, preform temperature, and melt temperature. The solidification time is a derivative from the primary parameters and the geometry of the mold, preform, and mold chilling scheme.

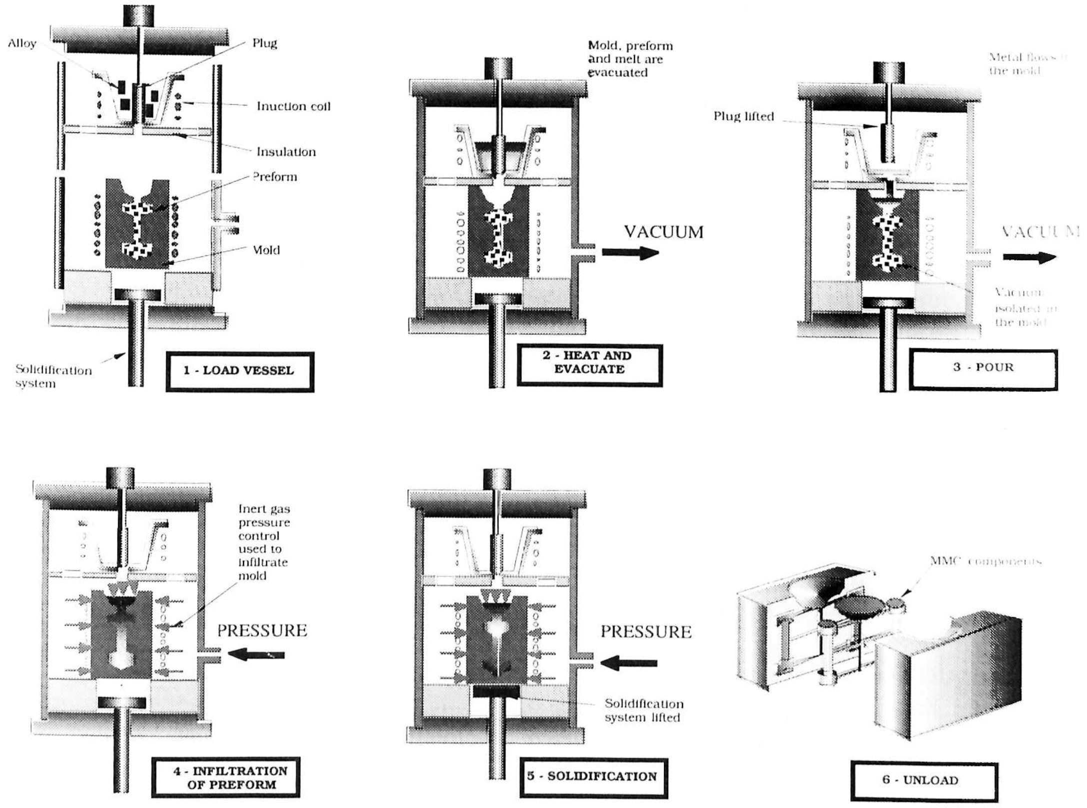

Figure 1 : Pressure Infiltration Casting of C/Al composites.

This process is unlike other MMCs production systems because the complete operation is conducted within the controlled environment of a pressure vessel. Controlled pressurization makes it possible to cast high fiber volume fraction and complex composite structures in thin wall, low strength moulds. The method and equipment used allow for inexpensive development and production of composite materials, prototypes, and near-absolute net-shape components.

3. SELECTION OF FIBERS AND MATRIX ALLOYS

The main limitation to the production of high tensile strength C/Al composite materials using casting processes is the reactivity of carbon fiber in molten aluminium which generates the formation of brittle **Al_4C_3** aluminium carbides at the interface [1], [2]. Published results [3], [4], have already shown that better properties can be obtained using high modulus graphite fibers from pitch precursor rather than PAN precursor carbon fibers. In this study, **K139 graphite fiber from Mitsubushi Kasei Corp.** was selected. It is also known that a decrease of preform and molten metal temperatures has a beneficient effect on the longitudinal tensile strength of the composite, due to the reduction of carbibe formation at the interface. Aluminium-Magnesium alloys are good matrix candidates due to their low melting temperatures, and their ductility. **Conventional Al-10wt%Mg casting alloy designated 520** was chosen here.

In order to produce locally reinforced components with high mechanical properties in the unreinforced areas, a **Al-7wt%Si-0.6wt%Mg alloy** was also selected. It is designated **A357** and is widely used as an aerospace cast part alloy in T6 conditions. It has been confirmed in a previous work [5] that the second phase silicon which precipitates in the inter-fiber region doesn't seem to have a large influence on the longitudinal mechanical properties of the composite due to the weak interface obtained when using high modulus graphite fibers.

4. MATERIALS PROPERTIES

C/Al composite plates, 60% fiber volume fraction, 160 x 80 x 2 mm in size were cast by AEROSPATIALE in order to optimize the infiltration conditions for each fiber/matrix couple. K139/520 without heat treatment, and K139/A357 T6 unidirectionaly reinforced composites were tested.

4.1. Longitudinal tensile strength of composites

The average tensile strength obtained at room temperature on a K139/520 composite was 1612 **MPa**. For K139/A357 T6, the average value was **1649 MPa**. In both cases, the Young's modulus was about **410 GPa**, and the fracture surface looked the same. An example of fracture surface is presented on figure 2, showing that the fiber/matrix interface delaminated and a pull-out mechanism occured, giving high longitudinal properties to the composites. Even when using A357 alloy as matrix, the second phase silicon precipitates, in the inter-fiber region, do not modify the behavior of the interface with K139 fibers and optimized infiltration conditions.

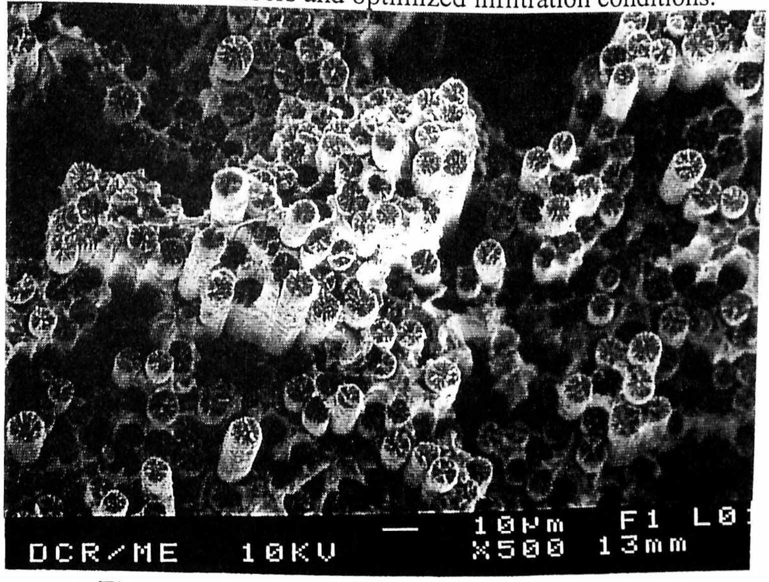

Figure 2 : Fracture surface of K139/520 composite (Ultimate Tensile Strength = 1716 MPa)

4.2. Temperature effect on longitudinal properties of K139/520 composite

Temperature effect on K139/520 composite was evaluated by ONERA on a material supplied by AEROSPATIALE. Longitudinal tensile tests were carried out on unidirectional composite plates. The results obtained are plotted on figure 3. The average tensile strength at room temperature, 1554 MPa, is consistent with the previous results. The average values, **1464 MPa at 250°C, 997 MPa at 300°C, and 970 MPa at 350°C**, confirm the thermal stability of the material.

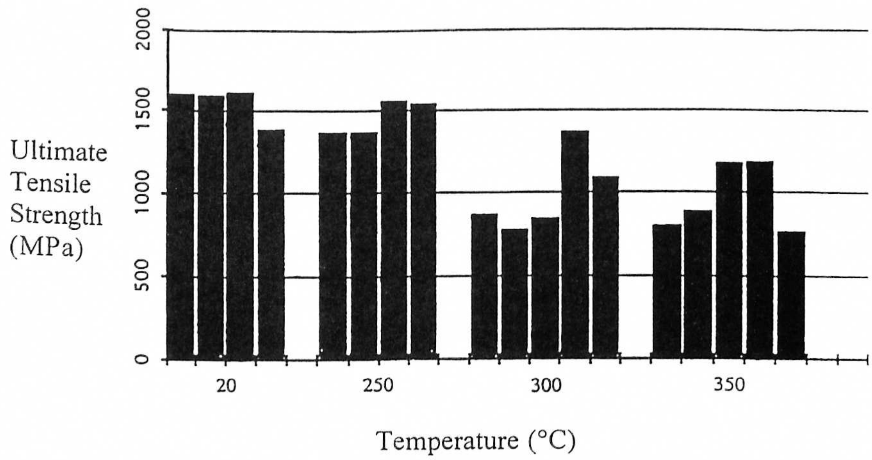

Figure 3 : Temperature effect on longitudinal ultimate tensile strength of K139/520 composite

4.3. Fatigue behavior of K139/A357 T6 composite

Fatigue tests, R=0.1 type under 30 Hz, were carried out by ONERA on unidirectionaly reinforced materials elaborated by AEROSPATIALE. The results are presented on figure 4. The **fatigue limit for 10^6 cycles is about 800 MPa. For 10^7 cycles, a 650 MPa limit is obtained**, which is over 6 times the fatigue limit of the unreinforced alloy.

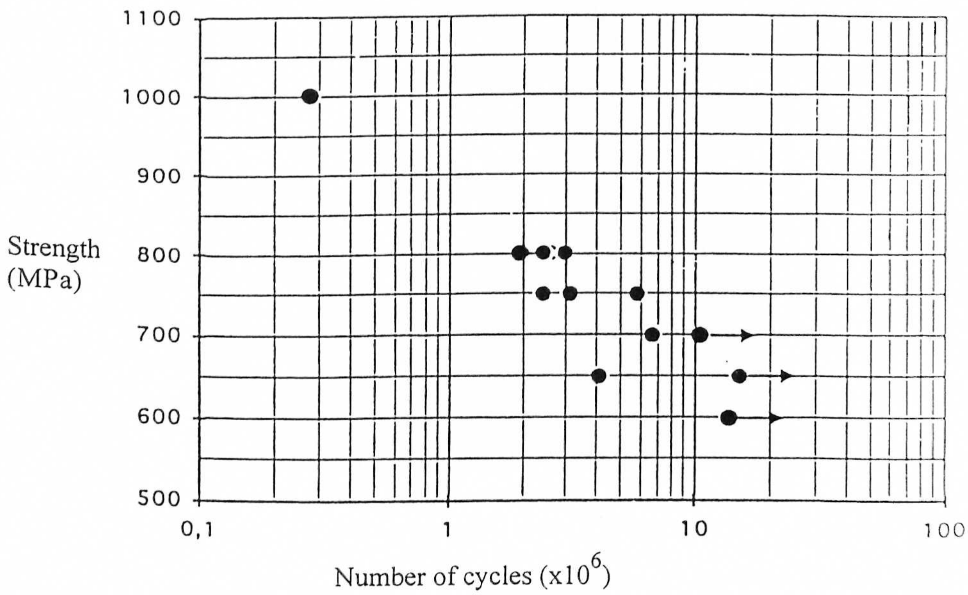

Figure 4 : S-N curve of K139/A357 T6 composite.

5. ELABORATION AND EVALUATION OF FEASIBILITY PARTS

5.1.Stiffened panel

A totally reinforced stiffened panel was produced using K139 graphite fibers and 520 casting alloy. The expected effect of the reinforcement was an increase of stiffness, tensile strength, and temperature resistance of the alloy. A composite part is shown on figure 5. The fiber volume fraction was 60% and the selected lay-up was an isotropic one in each area of the component.

Room temperature tensile tests were carried out on specimens cut from the part in order to check the properties of the material in different areas. The average ultimate tensile strength obtained was **377 MPa**, with an associated Young's modulus of **159 GPa**. The material properties were slightly higher in the base plate, in the direction of the stiffener, but no difference was shown between the 3 mm and the 6 mm thick zones.

So, using a graphite fiber isotropic preform, the stiffness of the matrix alloy has been multiplied by two, and the Young's modulus measured is close to the data of 167 GPa calculated with the elastic theory of laminates.

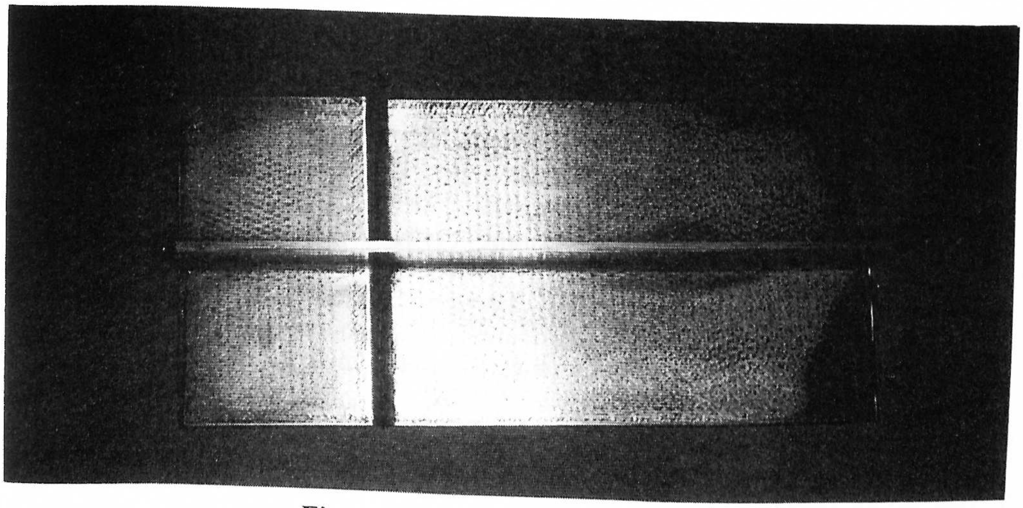

Figure 5 : C/Al stiffened panel

5.2. Attach fitting component

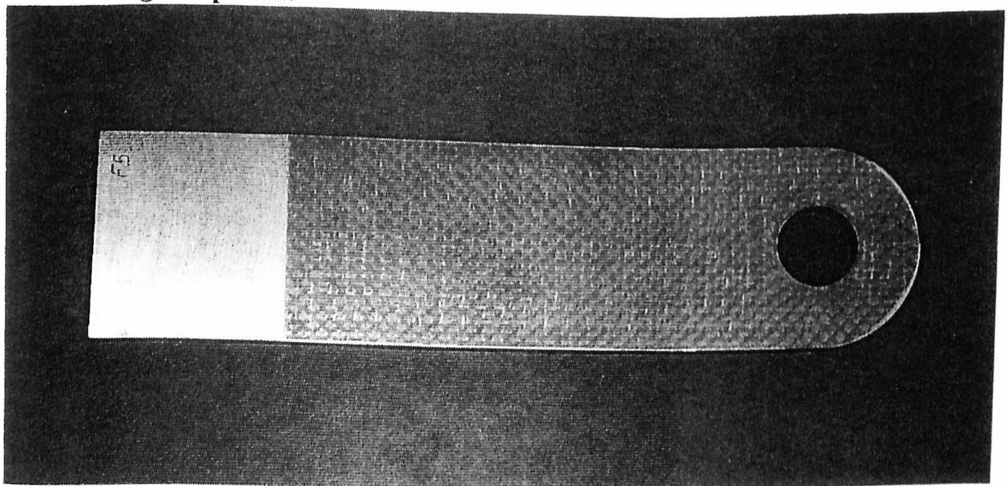

Figure 6 : C/Al attach fitting component.

A C/Al composite part is presented on figure 6. It is a locally reinforced part, made from a K139 graphite fiber preform and A357 alloy. The goal of the reinforcement is to increase the fatigue limit of the A357 T6 casting alloy. The fiber volume fraction in the reinforced area was

60%, and the selected lay-up was 35% of fiber in 0° direction, 30% at 45°, 30% at 135°, and 5% at 90°, 0° being the length direction of the component.

Fatigue tests, R=0.1 type under 10 Hz, were performed on this component in T6 conditions, using an axis to introduce the load. On a reference A357 T6 cast component, without reinforcement, the failure was obtained after 181640 cycles at 80 MPa. This result is in accordance with the fatigue limit of the A357 T6 investment cast alloy. On the reinforced part, **the failure occured only after 1095490 cycles at 80 MPa and additional 707792 cycles at 150 MPa, 200616 cycles at 200 MPa, and 2006 cycles at 250 MPa.**

6. CONCLUSION

Aluminium matrix composites plates and feasibility parts were elaborated using a gas pressure infiltration casting process and preforms of carbon fibers. An ultra high modulus graphite fiber was used in order to avoid a strong chemical reaction between reinforcement and liquid metal resulting in carbide formation. Aluminium-Magnesium alloys were chosen due to their low melting temperature and their high ductility. A conventional Aluminium-Silicon-Magnesium casting alloy was also used to produce locally reinforced feasibility parts.

Room temperature and high temperature (up to 350°C) tensile tests were performed on unidirectionally reinforced plates in order to determine the Young's modulus and the ultimate tensile strength of the composite materials. The results (410 GPa average Young's modulus, and 1630 MPa average ultimate tensile strength at room temperature) were compared to litterature data on carbon fiber aluminium composites elaborated by casting processes [1][2][3][4][5][6], and demonstrated the interest of the selected materials and process.

The fatigue behaviour of composite materials was evaluated using R=0.1 fatigue tests on unidirectionally reinforced plates. A fatigue limit of 800 MPa for 10^6cycles was obtained, showing the strong impact of the reinforcement.

Following the study of materials properties, two feasibility parts representing aerospace applications were elaborated and tested : a stiffened panel, and an attach fitting component. The goals were the increase of stiffness on the sheet structure, and of the fatigue resistance on the bolted structure. The mechanical characterization of both components demonstrated the benefit of carbon fiber reinforced aluminium composites upon conventional materials when low density, stiffness or fatigue resistance at medium temperatures are requested.

7. ACKNOWLEDGMENTS

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