COMPOSITE MATERIALS FOR STRUCTURAL LANDING GEAR COMPONENTS

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ABSTRACT

The paper presents the developments at SP aerospace of advanced landing gear components using composite materials.

Composite materials are widely used in the aerospace industry. The application however of composites within a single load-path primary structure, such as the aircraft landing gear system, is far from common. Developments in new composite materials and new manufacturing techniques offer improved characteristics and design potential, for the application of these materials in Structural Landing Gear Components.

The unique possibilities of composite materials to increase performance of landing gears offer great potential. Advantages include substantial weight savings, optimized material characteristics, high corrosion resistance, and potential cost reduction. To explore these possibilities a range of composite landing gear components have been developed at SP aerospace, resulting in the world's fist flight with a Polymer Matrix Composite (PMC) Drag Brace, as well as the first flight with a Titanium Matrix Composite (Ti-MMC) Drag Brace.

By developing these products it was demonstrated that weight savings of up to 25% are possible with polymer based composites, compared to ultra high strength steel. Using titanium matrix composites reductions of up to 40% were demonstrated. By intelligent design and development of suitable manufacturing processes, the cost of polymer based composite components were shown be comparable (or lower) than traditional high strength materials.

Composite Landing Gear components are ready for takeoff!

Main Heading

Background

Although the use of fiber reinforced composite materials in landing gear applications has been under investigation for several years, until now this technology had not reached the maturity status of clearance for flight in primary structural application in landing gears. Due to the ever increasing demands on low weight and low life cycle cost, SP aerospace identified composite technology for use in landing gears as very promising in the medium to long term. Therefore a technology development program was started to show the feasibility of composite materials in this application. This program was partly funded by the Dutch government. To assure maturation of this technology up to its final stages, the decision was made to continue development up to full flight clearance qualification, validated by actual flight testing.

Figure 1: Touchdown of PMC lower drag brace

Technology Roadmap

SP aerospace has established a Technology Roadmap to guide the technology development process. One of the appointed key elements is 'Affordable Light Weight Components'. Within this technology area, SP aerospace has been active in developing material applications for landing gears both in Polymer Matrix Composite (PMC) and in Titanium Matrix Composite (TiMMC).
To be able to compare the performance of both the PMC and TiMMC applications, the Lower Drag Brace of the F-16 main landing gear was used as a reference component. This structural landing gear component is manufactured in ultra high strength steel (for the heavy-weight version of the F-16).

Figure 2: Touchdown of TiMMC lower drag brace

The PMC technology development program resulted January 2001 in the world's first flight of a structural PMC component in a landing gear. In June of 2003 the world's first flight for a TiMMC component was accomplished.

Material description

Both programs described earlier were focused on the application of fiber reinforced composite materials. This is a generic term for a wide range of materials, which consists of closely packed extremely strong fibers, that are bonded together by a matrix material. In cases where the loading on (and stresses in) a component are highly directional, fiber reinforced composites can offer very large weight reductions compared to traditional steel or aluminum. The reasons why composites have not been used in structural landing gear components before are their relative complexity, the very large thicknesses required for the highly loaded parts, the high costs (both in material and labor), and the fact that landing gears components are PSE's (principle structural elements) and single load path and therefore safe life components. Since the composite materials used in both programs are of a very different type, both will be briefly described below.

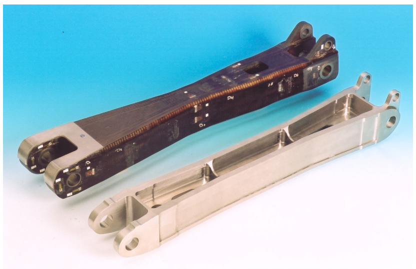

Figure 3: PMC and TiMMC drag braces

PMC = Polymer Matrix Composites

This type of fiber reinforced composite is the most widely used, and has gained a very strong position in aerospace, especially for the empennage and wings. In most cases either glass or carbon fibers are used in an epoxy matrix. The resin and fibers are combined into an intermediate product called prepreg, which is stacked into molds and cured under elevated temperature and pressure. Although this process is very controlled and suitable for large areas, is not very suitable to the often complex geometry of landing gear components. The last few years however the Resin Transfer Molding (RTM) process has developed to the extent where application in structural aerospace components has become feasible. In this process the fiber reinforcement for a product is first build up completely and later injected with resin in a mold. This offers the potential of reduced cost, large product thicknesses, and high and repeatable quality. The materials used for the technology demonstration components were non-crimped fabrics from intermediate modulus carbon fiber, and epoxy resin for use with RTM. A mold concept was used that enabled high rate manufacturing (three products per day), consisting of simple, interchangeable inner molds and a universal outer mold with heating system. SP aerospace works closely together with the Netherlands Aerospace Laboratory (NLR) utilizing their extensive experience in application and manufacturing of PMC materials in aerospace.

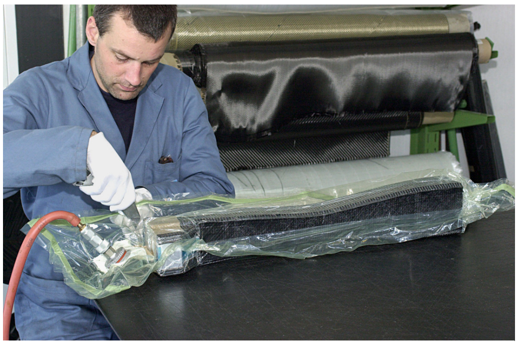

Figure 4: Preforming of PMC LDB

TiMMC= Titanium Matrix Composites

Metal Matrix Composites are metals that are locally reinforced with fibers, particles or other forms of reinforcement. For the highly loaded landing gear components, titanium (Ti) with continuous Silicon Carbide (SiC) fibers provides an optimal combination. This variant is called TiMMC (Titanium Metal Matrix Composite). Especially in stiffness driven applications this leads to extreme weight savings, because of the high stiffness to weight ratio.

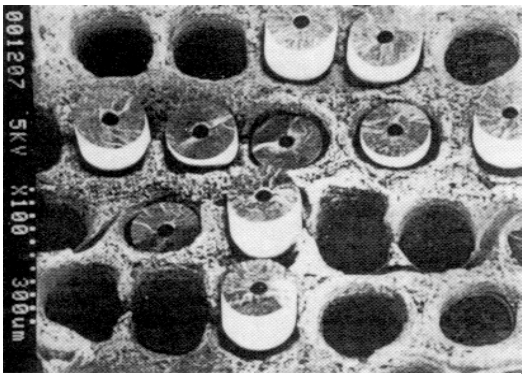

Figure 5: TiMMC fracture surface

SP aerospace has developed several components in TiMMC material in co-operation with leading TiMMC material suppliers, such as Textron Systems Composite Products Group (Wilmington, Massachusetts) and FMW Composite Systems, Inc. (Bridgeport, West-Virginia). For the TiMMC F16 Lower Drag Brace Silicon Carbide fiber SCS-6 was chosen, with Titanium-6Al-4Sn-2Zr-4Mo matrix.

Material properties

Fiber reinforced materials in general offer several advantages over conventional materials, but to be able to use these advantages in primary structural applications, considerable more knowledge about the material and its properties is required. Due to the non-isotropic material behavior, extensive effort is required in stress analysis, FEA is more complicated, and more material testing is required. Due to the fact that both TiMMC and RTM processed PMC are relatively new, there are limited material data available. Therefore in both development programs substantial coupon test programs were executed to obtain all the required material properties. The material test programs also covered all other relevant characteristics, such as damage tolerance, flaw tolerance and inspect-ability. Since the parts had to be qualified for flight, sufficient numbers had to be tested to obtain sufficient statistical confidence.

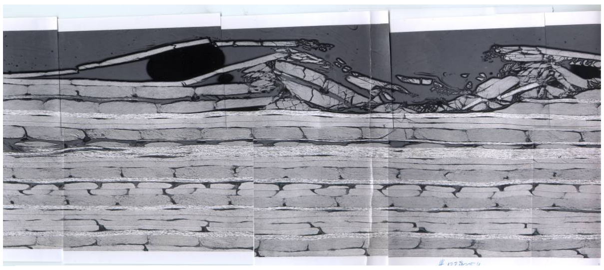

Figure 6: Impact damage PMC component

Design

In components designed for composite materials, special attention has to be given to the influence of the manufacturing process on the design. For each process a preferred geometry can exist, resulting in very different components for the same application.
This aspect is very apparent in the PMC component. Because of the RTM manufacturing process, a closed box-type section was more suitable than the traditional H-shape. Of course a detailed FE analysis was performed, taken the anisotropy and layering of the materials into account. Additionally an optimization routine was used on the FEA model to reduce weight of the design even further.
The overall layout of the TiMMC component is more traditional, since the H-shape cross section was very suitable for the manufacturing process. Using Pro-Engineer 3D design software and ABAQUS non-linear FE analysis, a detailed

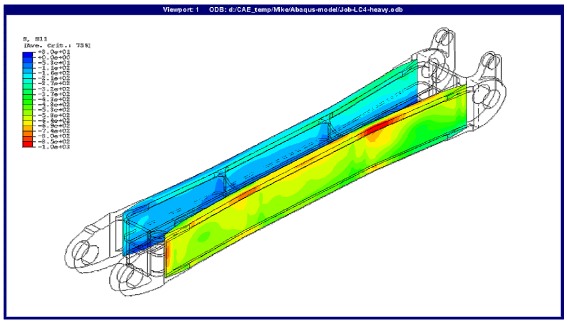

Figure 7: ABAQUS FEA of TiMMC component

design was made that addressed all TiMMC specific design characteristics, including internal stresses due to differences in thermal expansion and fiber drop-offs.

Manufacturing

Each of the components had its own challenges with respect to manufacturing. For the PMC component much effort was put into making the tooling suitable for high rate manufacturing at low cost. For the TiMMC component the high internal thermal stresses and controlling the deformations during machining were a high priority. A special manufacturing technique, supported with analysis methods was developed to compensate for deformations and control the positions during machining.

Figure 8: Injection mold for PMC LDB

Validation

To reach flight clearance for the components, an extensive test program was executed. The flight clearance tests were executed at SP's in-house test facilities, to check behavior, strength, fatigue, and failure modes of the components in a combination with adverse environmental and imposed damage conditions.

Flight test

The flight tests themselves were performed by the Test Flight Office of the Royal Netherlands Air Force, located at Leeuwarden Air force base. The RNLAF has one of their B-model F-16s modified with extra test equipment. It has real time data gathering equipment on board, so that sensors in a range of locations on the aircraft can be used and can also be monitored during flight. The Netherlands Aerospace Laboratory (NLR) prepared the dedicated in flight test instrumentation.

Figure 9: Test pilot in front of PMC LDB on F-16

After standard integration tests, to verify correct retraction of the modified landing gear, the instrumentation on the landing gear was installed. This consisted of accelerometers and strain gauges on both the standard and modified side of the landing gear. The signals from these sensors were used to verify the dynamic behavior of the landing gear.
Several taxi tests were performed, gradually increasing taxi speed and brake application. During the flight test the same build-up approach was used, gradually increasing vertical landing speed (and thereby loads). In all cases both the loads and the dynamic behavior of the drag brace were as expected.

Figure 10: TiMMC LDB installed on F-16

Weight/Cost evaluation

What the most suitable material is for each application and function depends largely on weight and cost constraints. PMC technology can offer a considerable weight reduction combined with comparable or somewhat lower price than steel. On the other hand the potential weight reduction for a TiMMC component is even larger, but at a price premium. TiMMC material cost is relatively high due to low volume production (see figure 11). Therefore both composite materials evaluated have their own position in the market.

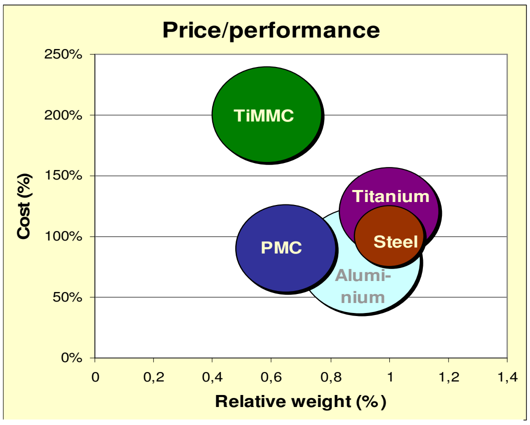

Figure 11: Price performance comparison

Other development programs

SP aerospace has established a Technology Roadmap to guide the technology development process. One of the appointed key areas is

Figure 12: Composite NH-90 trailing arm

'Affordable Light Weight Components'. The development of composite drag braces in both PMC and TiMMC material as described earlier in this paper, are a part of this technology area. Other programs have been performed (or are still running) to concentrating on specific targeted issues within this technology field. These include the use of composites as energy absorbing material (used for the NH-90 transport helicopter Nose Landing Gear) and as material for a complex shaped trailing arm (NH-90 Main Landing Gear).

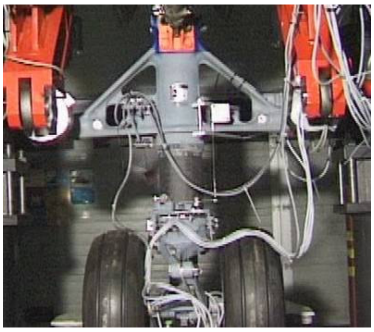

Figure 13: Drop test of NH-90 NLG with composite crush tube

Biography

SP aerospace, Performance under Extremes

Within the aerospace industry, SP aerospace acts as system design responsible for complete landing gears (NH90 Helicopter landing gear) and co-developing and co-manufacturing partner for system integrators of landing gear and other aerospace equipment related to defense and civil aviation markets.
Innovations such as advanced composites "for performance under extremes" are part of our approach to provide added customer value. Through our integral approach of engineering, development, manufacturing, and maintenance we are, by tradition, accustomed to perform under extremes for our customers.

Tjaard Sijpkes (Manager Technology & Development)

Mr. Sijpkes graduated from Delft University of Technology in mechanical engineering, Masters level, as a vehicle dynamics specialist. Mr. Sijpkes has been with SP since 1986 and has served as dynamics specialist and analyst. International experience was gained as a liaison engineer at General Dynamics working a.o. on the landing gear of the F-16. In 1990 the responsibility for all landing gear development was taken over and in 1993 all aerospace development activities were placed under his responsibility. Aerospace programs where he was involved in are a.o. Fokker 50 and 100, F-16, Airbus 330/340, N-250, BAe-125, Embraer ERJ-145, NH90 helicopter and JSF.

Peet Vergouwen (Senior Development Engineer)

Mr. Peet Vergouwen graduated from Delft University of Technology in Aerospace Engineering. Mr. Vergouwen has worked as a composites designer and manufacturing specialist for about 10 years at several different aerospace companies, before starting at SP aerospace in 1990. He has been project manager for the TiMMC lower drag brace project and the PMC trailing arm.