INDUSTRIALIZATION OF A CARBON COMPOSITE CONTROL ROD

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SUMMARY: The South African Composites Industry has huge potential for growth due to the relative low labor cost and huge labor force. These advantages are, however, opposed by import costs on materials due to the fact that no advanced composite materials are produced in the Republic. The only way therefore to remain competitive is to develop processes, which are industrialized and minimize complexity, skills requirement and eventual labor cost. This paper illustrates, on a small scale, the industrialization philosophy followed in the production of carbon composite control rods for the Rooivalk attack helicopter. The industrialized component was designed almost entirely from a manufacturing point of view with extensive testing to prove certain critical design requirements. The finalized product could be manufactured in series production at a cost well below that of existing or potential suppliers.

KEYWORDS: RTM, braiding, industrialization, ballistic tolerance, fatigue, computer controlled curing

INTRODUCTION

The Rooivalk attack helicopter features carbon control rods as part of the ballistic survivability requirement placed on the overall control system. A research project aimed at local manufacturing of advanced composite components was performed by Denel Aviation to establish the viability of local manufacture of this specific component. The development specification for the component [1] had to be met or exceeded and a definite cost advantage proved. In order to achieve these requirements within a limited research budget, it was clear that the following aspects must be addressed:

- Minimal skills requirement
- Minimal integrity risk due to process variables
- Controlled curing
- Economic material system
- Integrated manufacturing instructions and training

Within these constraints, it is clear that structural optimization and lengthy finite element analyses would be premature if at all required, and a philosophy of experimental manufacturing concepts and structural testing was followed. It is realized that this philosophy cannot be projected onto larger more complex components, but due to the simple load conditions and requirements for the rod, it proved to be economical.

DESIGN REQUIREMENTS

The dominating design requirements were identified as the following:

Static strength

The ultimate design load for the rod is 780 kg, which is a once off control system failure design case.

Ballistic requirement

The ballistic requirement is for a single shot 7.62 mm caliber and a single shot 12.7 mm caliber fired at the following locations in the center of individual separate rods:

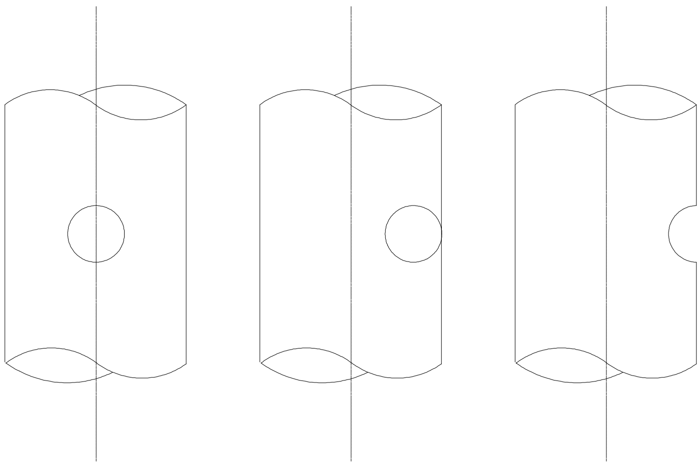

Figure 1 : Ballistic damage locations

It is required for the rod to survive the ballistic shot and a static load of 70% of the design load with the ballistic defects as illustrated present.

Fatigue loading

A block loading fatigue spectrum for the rods are defined in the development specification representing a typical mission manoeuvre flight and repeated to represent 10,000 flying hours. For the purpose of the development, the most severe load in the spectrum would be applied to represent the total expected lifetime. This required 800 000 cycles of $\pm$ 430 N at temperature extremes of –40°C and 80°C.

STRUCTURAL CONCEPT

Metal/Composite interface

The rod is of the adjustable end type and the most critical area was defined as the load transfer between the metal insert containing the screw thread and the composite material involving co-cured bonding. The initial structural concept is illustrated in figure 2.

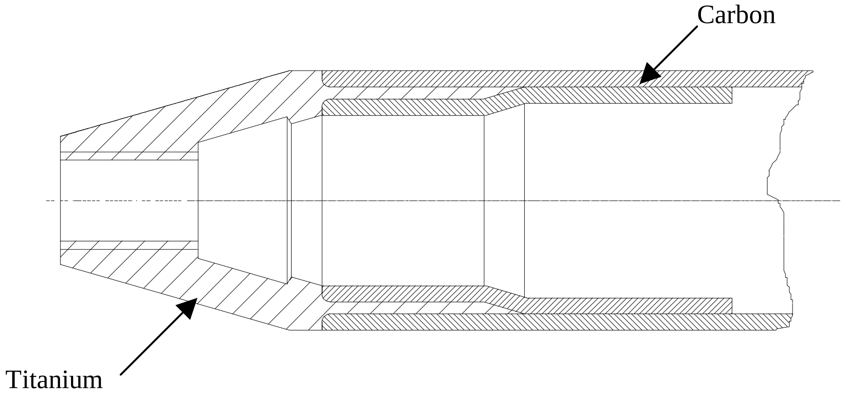

Figure 2: Control rod end cross-section

This concept proved to be robust and reliable in temperature variations although thorough care must be taken in bond preparation and lamination of the internal plies. The structural integrity of the rod relies heavily on bond quality, which was immediately identified as a risk area.

The ballistic shot fired at this rod , although not required by the specification, highlighted severe risk in total failure, should the rod be hit at the metal/composite interface. Figure 3 illustrates the damage done by a 12.7mm glancing shot fired at the interface.

Figure 3: Damage resulting from 12.7mm ballistic impact

These two factors initiated a design that would minimize the risk of ballistic damage and bond quality by limiting the insert length to the rod end screw-in length and pursuing a mechanically locked insert instead of a bonded load transfer. The resulting rod end structural concept is illustrated in figure 4.

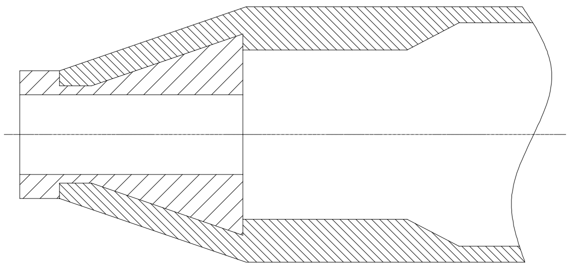

Figure 4: Mechanically locked insert rod end design

MANUFACTURING PROCESS

Material Selection

Experiments were conducted using pre-impregnated materials, resin film infusion and resin transfer moulding (RTM). The RTM process was favored as lamination of dry braiding and unidirectional tape produced preforms quickly and low temperature curing could be performed.

The materials selected were:

- Carbon braiding (92 strand, diameter 27)
- 50mm wide glass stitched carbon UD tape
- Araldite 560/564 epoxy resin system
- CYTEC BR127 bonding primer

Tooling system

An integrally heated aluminium tool with computer controlled heating, vacuum, internal bag pressure and injection pressure control was used to control the injection and cure sequences.

Lamination procedure

The rod ends and shaft sections are laminated separately as illustrated in figure 5.

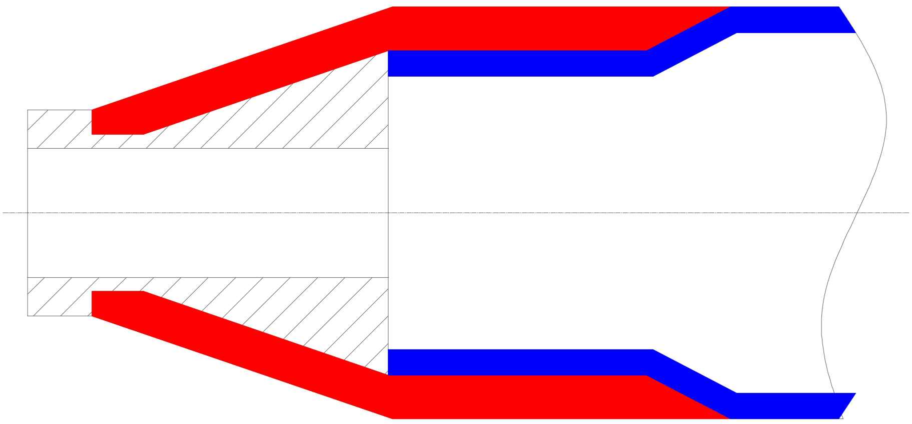

Figure 5: Rod end and shaft preform assembly

The final assembly of the three preformed parts with the nylon inflation bag is shown in figure 6.

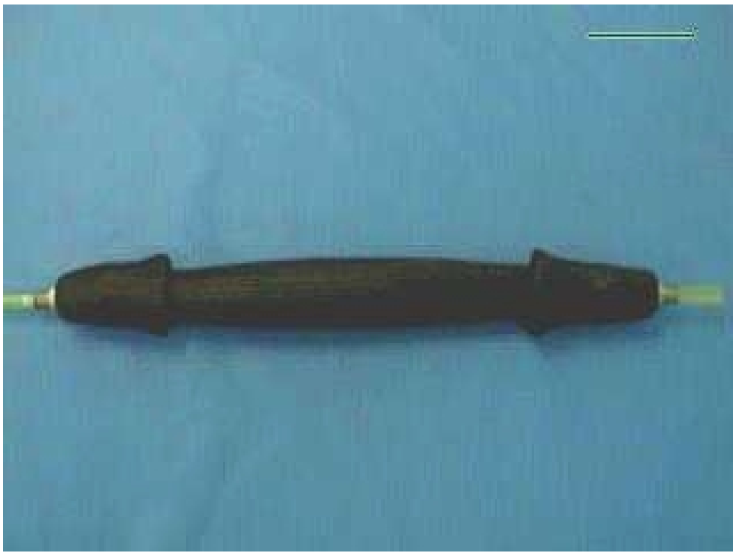

Figure 6: Completed rod preform

The preform is loaded into the tool and the injection and curing sequences initiated. The injection is done at 0.5 bar pressure with an internal bag pressure of 0.5 bar and a vacuum of 0.4 bar and a constant temperature of 60°C. Once the resin has been injected, the internal bag pressure is increased to 6 bar and the vacuum line to 0.7 bar. The tooling system is illustrated in figure 7.

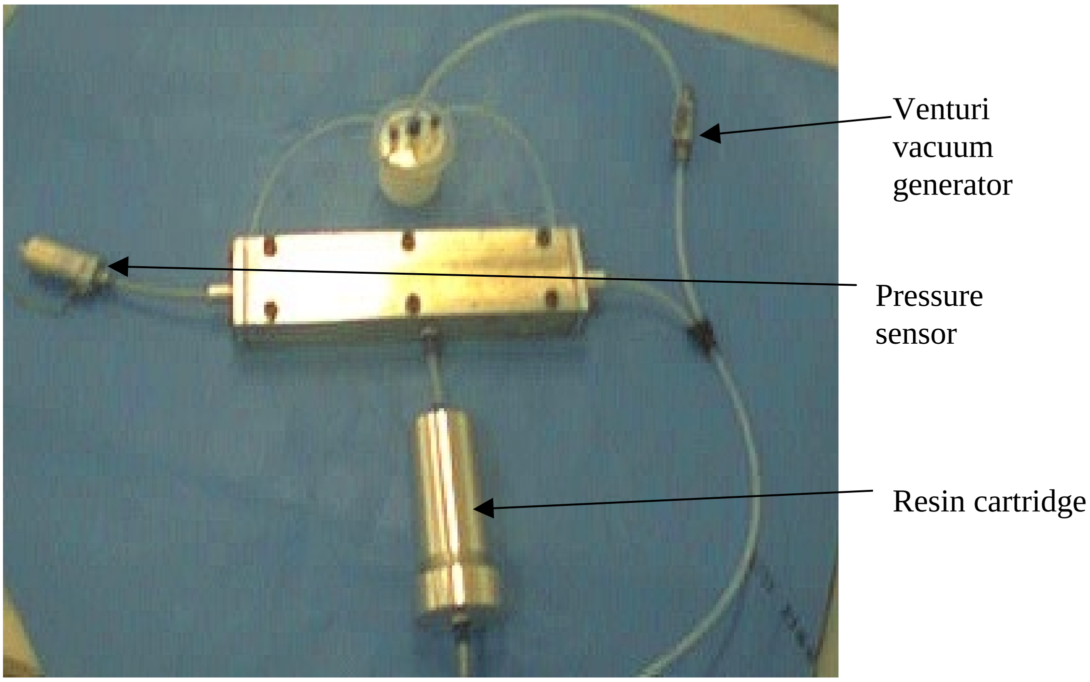

Figure 7: RTM tooling system

Manufacturing instructions

A detailed visual instruction sequence containing photographs, drawings, material specifications, standard composite manufacturing procedures and health and safety precautions, guides the manufacturer step by step through the process before the computer takes over the injection and curing sequences.

This system was specifically designed for people with little or no previous experience of composite manufacturing and is viewed as an excellent means for training new people to manufacture the rods.

A cure cycle history is printed out with each rod and a rundown of time taken per manufacturing process can be obtained to evaluate the level of skill of different manufacturers and identify problem areas early in the training phase

ROD EVALUATION

Static test

The rod was tested in tension and compression and failed each time in the shaft well above the desired design load with the shaft lamination being [braiding/UD/braiding], in contrast to the initial design in which the failure mode was that of the insert pulling out in tension.

The maximum load obtained for the improved design in tension was 2900 kg and 2100 kg in compression where compression failure just beneath the insert occurred.

Ballistic testing

The rods all survived the direct impact of the ballistic shots with minimal damage propagation around the holes as illustrated in figure 8, showing from left to right, 7.62mm through the center, 7.62mm off center, 12.7mm through the center and 12.7mm glancing shot.

Figure 8: Ballistic impact damage

All rods passed the 70 % load except the 12.7mm glancing shot which failed at 40% design load due to the eccentricity in load caused by the shift in neutral axis in the remainder of the rod, which can be resolved by adding additional UD plies to the shaft section.

Fatigue testing

A cyclic load of 43kg was applied for 800,000 cycles after which the rod was cooled to –40°C and the tests repeated. The test was performed at 80°C without failure. The load was subsequently increased to ± 100 kg and eventually to ± 200 kg without failure occurring. The fatigue test setup is illustrated in figure 9.

Figure 9: Fatigue test setup

A final test was done without bond priming the inserts and run at 1000,000 cycles without failure and degradation, proving that the insert is indeed mechanically molded into the rod and does not depend on adhesive bond quality.

CONCLUSIONS

It is concluded with this study that by means of engineering a component from the manufacturing/producing end of the process, a good understanding of the problems involved with production of the components can be obtained quickly and their impact on the design assessed, before going into detailed structural analysis.

Minimizing risk in structural integrity was integrated into the design by mechanically moulding the inserts into the component, which means a higher degree of repeatability can be obtained.

Defining ease of manufacture as a prime objective coupled with some structural calculations and substantial testing, in this case, lead to a successful design with extremely simple manufacturing steps making the local manufacturing of these components viable with even unskilled people.

It is emphasized again, as a conclusion, that in order for the local advanced composites industry to be globally competitive, much thought has to be put into the manufacturing processes of components and an integrated approach together with the structural designers has to be followed to reach compromises for the common goal of economic viability.

REFERENCES

1. Kruger, F.J. , Fatigue Spectrum for Control Rods, Doc No 08C6700RV0004, Denel Aviation, 1995-09-08