Paper Title: Strategic Opportunities and Challenges for Composites R&D in South Africa – A CSIR Perspective

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Abstract

The utilisation and prominence of composite materials have been increasing significantly over the past decade in technologically demanding industry sectors, such as aerospace and automotive. It has been accompanied by growing needs for research and development on these materials and their applications to push the boundaries of achievable material and component properties. A similar trend has been observed in the construction industry with regard to the overwhelming demand for housing on the African continent. These factors as well as the current national and global industry trends highlighted the need for a clear strategy to guide the CSIR's research and development role in support of these sectors of the South African economy. This paper positions the development of a CSIR strategy in the national strategic context, taking into consideration the national drivers and the challenges faced by the local industry. CSIR's strategic approach and future focus are explained against the background of the organisation's track record in composite material development and application, analysis of its current strengths and alignment with its strategic intent. The drive towards utilisation of natural fibres in composites, the role of nanocomposites and opportunities for composite-metal hybrid materials are discussed. Some examples of recent research aligned with this strategy are also given.

Keywords: Composites R&D, CSIR strategy, natural fibre based, fibre metal laminates

INTRODUCTION

Technologically demanding industries, such as the aeronautical and automotive sectors, have over the past decade been increasing their demand for lighter, stronger and smarter materials and structures. The requirements of new aircraft such as the Airbus A400M and the Boeing 787 Dreamliner, as well as technological advances requested by automotive companies, such as Daimler-Chrysler, BMW and Volkswagen, have been strong drivers in these sectors. Due to a growing demand for housing, including alternatives that could be more affordable without compromising safety, the construction industry has also been calling for advances in materials of construction. Simultaneously, the imperative to utilise environmentally friendly materials and manufacturing processes has grown in prominence. New military applications in the fields of post-conflict reconstruction, ballistic or blast protection and others have raised new materials challenges.

This combination of market needs has stimulated research and development efforts in the fields of advanced metals and composites, together with design improvements to optimise manufacturing technologies with resultant cost reduction and shorter delivery times. The unique characteristics of materials such as titanium alloys and advanced composites have led to intensive research on matching properties with application requirements. Manufacturing processes, such as near-net shaping, forming of high integrity thin-walled structures and high performance machining, have received serious attention.

While the CSIR has a proud track record of achievements in the application of composite materials and structures culminating towards the end of the previous century, activity in the field has declined dramatically during the first half of this decade. However, more recently the national priority given by strategies, such as the Advanced Manufacturing Technology Strategy (AMTS), to the aerospace and automotive industry sectors, coupled with the need for research and development in support of local industry growth expressed by various players in the South African composites industry, have placed composites squarely on the CSIR's agenda. Consequently, over the past eighteen months, a task team has developed a CSIR Composites R&D Strategy to focus and coordinate the organisation's activities in this field.

THE CSIR TRACK RECORD

The CSIR's track record in composites includes a large number of products and technology demonstrators, including the development of several aircraft and major aircraft components. Two examples are presented which illustrate the type of work undertaken.

The first example is the OVID aircraft, an all-carbon fibre composite technology demonstrator, as shown in Figure 1. This was a turboprop powered tandem two-seat trainer that was developed by Atlas Aircraft and the CSIR. The combined team was led by Atlas, who also determined the aerodynamic lay-out. The rest of the design and development was undertaken at the CSIR premises.

Figure 1: The OVID Aircraft in Flight

The main aim of the project was to develop the technology to design and build this type of aircraft using the expertise available in South Africa. Composites were an attractive choice due to their low tooling cost, low parts count and speed of prototype work when compared to similar aluminium aircraft.

The cross section through the wing, as shown in Figure 2, gives a good idea of the structural philosophy of the aircraft. The skins are all Nomex stabilised, which eliminates the requirements for integral stiffeners, thus reducing the complexity and manufacturing costs while improving the damage tolerance.

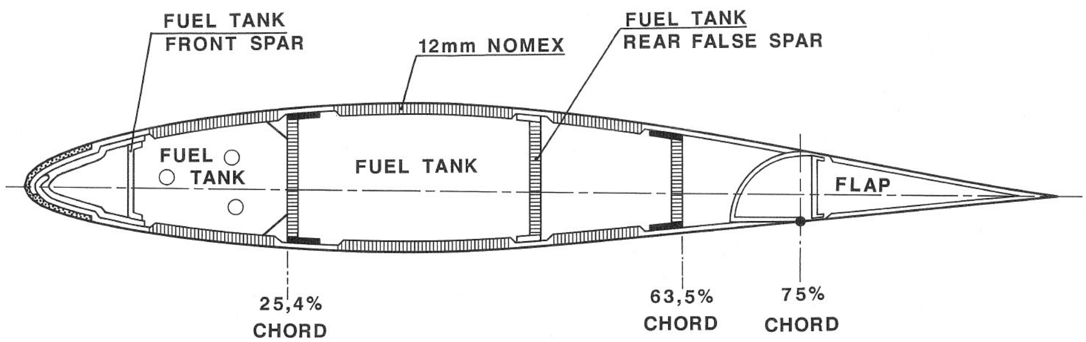

Figure 2: Wing Cross Section

The next example is a RP35 type fuel drop tank for the wing and centreline stations of the Mirage F1 aircraft. These tanks contain approximately 1 200 litres of fuel and are required for long range operations. [1]

To investigate the feasibility of local manufacture, the CSIR constructed three prototype drop tanks from carbon fibre. The first tank was purely for structural tests and contained no fuel or electrical systems. The following two tanks were fully equipped with fuel and electrical systems. Figure 3 shows the first prototype.

Figure 3: Drop Tank Prototype

The original RP35 drop tanks were manufactured in aluminium, and it was decided to carry out a feasibility study to determine whether the new drop tanks should be manufactured from composite materials or aluminium. Composite materials were selected for this application for the following reasons.

- Relatively low tooling requirements and cost for complex shapes.
- Good corrosion behaviour with moisture and fuel.
- Lower likelihood of suffering catastrophic structural failure due to a hostile strike.
- Good retention of strength with time after an impact
- There was greater scope to tailor the structural dynamics of the new drop tank design to the original so that flutter clearance work would not need to be repeated.

Prepreg materials showed greater promise than wet lay-up systems due to their repeatability, both from a material property and manufacturing point of view. Plain weave fabrics and unidirectional tapes of T300 type fibres were selected.

CURRENT CSIR EXPERTISE AND FACILITIES

An internal audit of the composites related capabilities and equipment that contribute to research in this field in the CSIR revealed existing or newly-developed expertise in the following areas:

Computational Structural Design, Analysis and Modelling

A strong competence in computer-aided design, finite element based analysis, simulation and modelling of components and structures exists for the prediction of the mechanical behaviour and expected service life of components and systems. Current work on the mechanics of reinforcements is focused on buckling, tensile and shear deformation of woven and nonwoven fabrics. Both force-balance and finite element approaches are used.

Mechanical Testing of Materials and Components

Laboratories for testing a range of mechanical properties of materials and parts are available, manned by a few individuals with wide experience.

Polymer Matrix Materials

A competence area with polymers as their main activity has existed in the CSIR for many years and strong capabilities both in materials development and materials application have been maintained.

Natural Fibre Based Composites

On natural and synthetic fibre reinforced composites, the CSIR is currently involved in development of thermoplastic composites for building industry applications, as well as for automotive and aerospace applications. Current projects involve use of flax, sisal and hemp fibre reinforcement in polypropylene and polyethylene matrices. Future work will be aimed at utilizing kenaf in addition to the above mentioned fibres and biodegradable matrices to make biocomposites. Different surface treatments to improve strengths and impact resistance of the materials will also be explored for load bearing applications.

Smart Structure Design and Analysis

Based on extensive experience in the field of sensor materials and sensing systems, the Sensor Science and Technology group is well-equipped to extend their work to composite based smart materials and structures. Embedding of sensors and actuators in resin-based composites offers interesting possibilities in this regard.

Nanofibre-based thermoplastic polymer composites

Work towards harnessing the advantages of both thermoplastic polymers and nanofibres in the form of nanofibre-reinforced thermoplastic polymer composites, has been done. A unique aspect of this research is the approach that is used for developing single material composites (both matrix and reinforcement are of the same polymer). This project makes use of the fact that certain polymers are available in both the crystalline and amorphous forms. Hence, when processing the polymer (crystalline nanofibres + amorphous matrix) into a composite, the crystalline nanofibres (higher melting point than the amorphous matrix) stay intact and one is able to obtain a single material nanocomposite.

Pre-form Development

The application of pre-forms and pre-pregs in thermoset composites is being explored. Both natural and synthetic fibres are utilized for the development of two-dimensional and three-dimensional performs for T-beams, I-beams and other structural parts as needed.

Equipment and Facilities

Some of the equipment and facilities available for research and development on composite materials are:

- Material and component test equipment
- Computing hardware and software
- Compounding, injection moulding and compression moulding machines
- A Laser Vibrometer
- Facilities for producing and characterising nonwoven fibre materials
- Fibre preparation and characterisation facilities
- Weaving and knitting facilities for pre-form development
- Prototype compression moulding
- Fibre reinforced composite characterisation equipment
- Polymer matrix characterisation equipment
- Bicomponent filament extruder
- A fire, smoke, toxicity testing laboratory
- Extensive facilities for research on nanocomposites

Apart from the above, a wide range of scientific analytical equipment is available in the organisation.

RECENT RESEARCH

Laminate damage initiation and growth

All structural components contain discontinuities that locally affect the stress state. These discontinuities are typically associated with fasteners, global design features and defects. In the case of intentional discontinuities, for example bolt threads or structural cut-outs, there are well defined and relatively gentle radii. The field of structural mechanics has well defined relationships for the analysis of the stress concentrations caused by these radii in order to ensure structural integrity. Defects, for example cracks, can however have very sharp radii, and using conventional relationships for the analysis of the stress near a crack tip can significantly underestimate the magnitude. The requirement for the analysis of defects has led to the field of fracture mechanics which combines the mechanics of the body with its mechanical properties.

The fracture of composite materials is characterised by both intralaminar damage (through the thickness of the laminate, including fibre damage) and interlaminar damage (delamination). Of these two, delamination is the most common form of damage due to the lack of fibres to arrest the crack growth. Prediction of composite life in service would therefore require both tests to characterise the fracture toughness of the material and analytical techniques to predict the delamination growth.

The research was initiated by carrying out tests to characterise two materials, namely Hexcel 8552/AS4 and Hexcel 6376/HTA carbon-fibre reinforced epoxy. These materials were tested for their tensile and compressive properties, and then for fracture toughness under mode I, II and mixed mode I / II conditions. [2] - [5]

With the materials fully characterised, the investigation into suitable methods for determining the delamination growth was carried out. The first step in propagation analysis is the determination of the stress intensity at the crack tip. An extensive investigation was carried out into various techniques for performing the fracture mechanics calculations. The most promising method was the virtual crack closure technique for strain energy density at the crack tip using the finite element method. A typical model is shown in Figure 4.

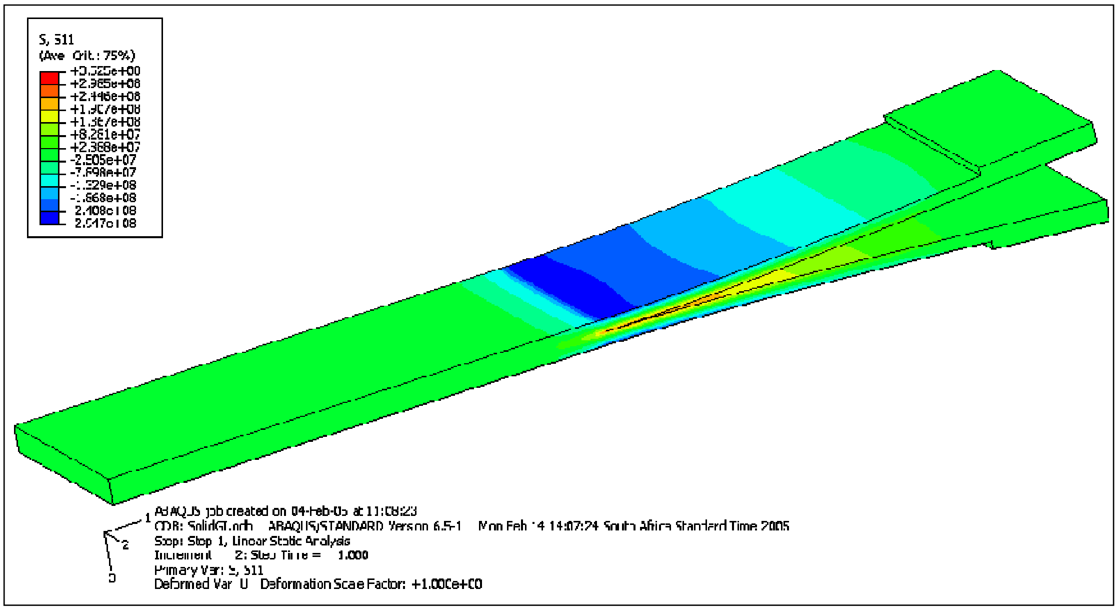

Figure 4: Fracture Model of a Laminate

Work is ongoing to predict the initiation of damage due to impact, and also the modelling of the subsequent delamination growth using new enhancements made to the Abaqus finite element software. Supporting tests are to be carried out on impact and blunt notch specimens.

Fibre Metal Laminates

Structural materials inherently have their strong points (e.g. strength and stiffness) and weak points (e.g. corrosion and impact resistance). One way to overcome these limitations is to combine different materials in a way that the strong points of the constituents are combined, but the weak points are minimised. An example of this approach is the combination of fibres and resins into a traditional composite material.

The two dominant high-end structural materials at the moment are light metal alloys and resin-based composite materials. An area of on-going research is on how these two materials can be hybridised into an even more advanced material. The objective is to achieve high strength and stiffness to weight ratios with good resistance to fatigue, corrosion and impact damage.

There is increasing pressure in the aviation industry to increase levels of safety while reducing the manufacturing costs. One enabling technology that is being applied to the new generation of airliners is that of fibre metal laminates (FML) [6], [7]. In these materials layers of thin metal sheets alternate with fibre-epoxy layers. This kind of material is starting to see application on emerging aircraft of the large manufacturers, Boeing and Airbus.

The conceptual basis for FMLs originated at Fokker during the 1950's. The company could not afford expensive production machinery in the wake of the Second World War, and resorted to bonded laminated structures instead of using monolithic machining methods. It was found that this type of structure had an increased resistance to fatigue, and the fatigue that did occur was mainly limited to the outside layer.

FML research was taken further during the 1980’s by the Delft University of Technology. The development concentrated on the use of thin aluminium sheets combined with fibre – epoxy layers. A typical lay-up is shown in Figure 5. The fatigue performance of an FML is critically dependant on the optimum ratio of aluminium to fibre. This is due to the means by which the laminate resists fatigue, namely the fibre-crack bridging mechanism. The stress intensity at the crack tip is reduced by crack closure stresses in the fibres. Fibre failure during crack opening is avoided by the shear stresses in the adhesive layer creating a controlled delamination.

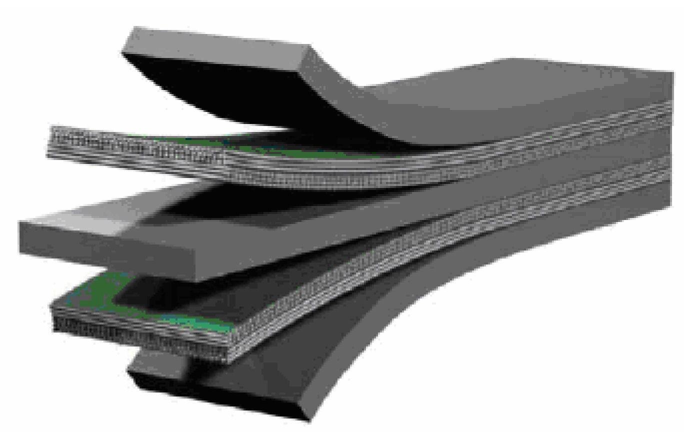

Figure 5: Typical Cross-Ply FML [7]

The first generation FML’s were designated ARALL. These laminates were based on 2024-T3 aluminium sheets of 0.3 mm thickness combined with aramid fibres and manufactured by ALCOA and AKZO. The aramid fibres were arranged in a unidirectional fashion due to the material being optimised for wing structures. During the 1980’s a full scale Fokker 50 lower wing panel was built and flown using the material, resulting in a 20 percent weight reduction. ARALL designs have also given a 30% weight reduction on the lower wing panel of the Fokker F-27 and a 23% weight reduction on a C-17 cargo door [8].

ARALL proved to be unsuitable for fuselage structures due to the poor compression properties of the aramid fibres. Compressive stresses are present in the laminate after curing during production, and cyclic compression of the fibres will occur even if the minimum stress on the laminate is zero. A second generation laminate was developed in 1987 for use in fuselages and was designated GLARE.

Deutsche Airbus tested an A330/340 fuselage barrel manufactured from the material in 1988/89. GLARE first flew as a bonded repair patch on a USAF C5-A in 1985. The first civil applications were as the bulk cargo floor of the B777 and the bulkhead of a Learjet

125. The material has subsequently been applied to the upper fuselage of the Airbus A380. GLARE is now a product of Structural Laminates Industries (SLI).

A further application of the FML philosophy is known as TiGr, which is a titanium graphite hybrid laminate [9]. A typical layout of this type of laminate can be seen in Figure 6.

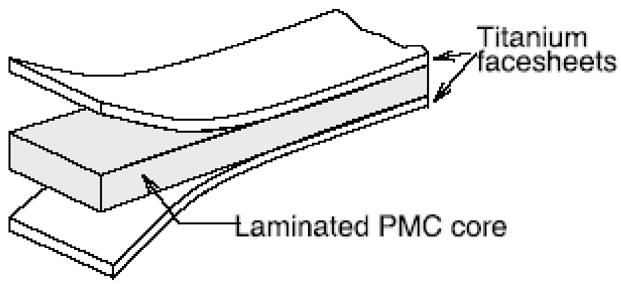

Figure 6: Titanium-Graphite Hybrid Laminate [10]

The initial research into TiGr was carried out under the NASA sponsored High Speed Research Program, which was orientated towards developing technologies for high speed civilian transport applications. The material was developed in order to gain specific advantages over traditional aerospace materials. Compared to aluminium structures it provides

- higher specific strength and stiffness;
- excellent fatigue and fracture properties similar to those of ARALL or Glare.

Compared to traditional fibrous composite structures it displays

- higher bearing strength;
- better impact resistance;
- improved resistance to environmental effects like water ingress, oxidation and UV degradation (this would only apply for the titanium layers being on the outside);
- strong indications that there would be an improvement in the resistance to lightning strikes.

A typical combination of materials used is reported in [11]. The outer titanium layers are the metastable beta titanium alloy, 15V–3Cr–3Al–3Sn (Ti 15-3), 0.127 mm in thickness. The fibrous composite plies are 0.142 mm in thickness and contain IM7e graphite fibres in the thermoplastic matrix, PIXA-M.

The various types of fibre metal laminates developed to date all incorporate continuous sheets of fibrous composite materials. This would make this class of material suitable for embedded sensors and actuators, resulting in smart structures.

R&D CONTRIBUTIONS BY THE CSIR

Based on the CSIR track record and the current expertise and research facilities, the organisation expects that it could contribute in the following fields:

- Development of novel composite materials, including renewable and biodegradable materials and processing methods for these materials.
- Development of novel applications of composite materials and structures, as well as the processing technology to produce these.
- Testing of composite materials and components to international testing standards.
- Engineering design, analysis and modelling of composite based components, assemblies and systems, including the ability to model manufacturing processes.
- Up-scaling of laboratory scale units to pilot plant scale and the technology transfer accompanying these.

CSIR'S STRATEGIC OBJECTIVES

In positioning strategically for sustainable research and development in the field of advanced composites in future, CSIR has set the following objectives:

- Build on previous investment and existing technology platforms to progress cost-effectively as rapidly as possible in the advanced composites field.
- Accelerate the development of human capacity for composites research and development.
- Perform research and develop composite technologies and products that will assist the South African composites industry to be globally competitive and provide solutions to local needs.

CSIR'S STRATEGIC R&D FOCUS

The future research and development activities of CSIR will be broadly grouped under the following strategic themes:

Natural Fibre-Reinforced Bio-Composites

CSIR has taken the lead, in collaboration with the DST, to establish a national project in this field.

Composite-Metal Hybrid Materials

A project to determine the scope and to confirm the feasibility of a research and development programme in this field, is in progress at CSIR. This will deliver a detailed plan of the CSIR's future focus in the broader research field.

Materials Testing to International Standards

The ISO 17025 Quality Management System accreditation of the current Mechanical Testing Laboratory of the CSIR will be extended to include testing of composite materials and components to international standards.

Nanocomposites

The CSIR and DST have invested jointly over the past two years in the establishment of a National Centre for Nanostructured Materials. One of the primary themes of this centre is research in the field of nanocomposites.

Development and Qualification of Novel Manufacturing Processes

In collaboration with research groups at universities and with the local industry, the CSIR is establishing standards for manufacturing processes that will comply with international best practice. New or improved processes will be developed, qualified and transferred to industry.

CONCLUSIONS

There exists a national awareness in South Africa of the role that advanced composites can play in industry sectors such as aerospace, automotive and construction. Strategic implementation initiatives like the AMTS have given impetus to research and development in this field, supported by the local composites industry. South Africa's largest R&D organization, the CSIR, has taken on the challenge to lead the national effort in composites R&D in selected areas and is well positioned to fulfill this role. In collaboration with research groups at universities nationally and internationally, other R&D players and the industry, the CSIR and its collaborators are actively working towards improving materials, structures and systems to provide novel solutions for the ever-increasing demands of the end-user industry sectors.

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