Advanced materials for application in the aerospace and automotive industries

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Abstract

The CSIR conducts research and development (R&D) involving advanced materials with applications in the local automotive and aerospace industries. The relevance of these R&D programmes is illustrated by positioning them in the context of key industry trends and drivers and South Africa's ability to respond to these. Examples of CSIR R&D on light metals and advanced composite materials, including the successes achieved in mobilising complementary expertise at universities in support of these projects, are given. Finally, the progress made and the impact already achieved or expected in future, are described.

1. Introduction

During the development of the Advanced Manufacturing Technology Strategy (AMTS), commissioned by the National Advisory Council on Innovation (NACI) in 2002, the need for national initiatives on advanced materials in support of the South African priority industry sectors was recommended. Two priority sectors identified by the Department of Trade and Industry (the **dti**) were automotive and aerospace.

The first of these initiatives to be established was the Advanced Metals Initiative (AMI) with four legs, namely light metals, precious metals, new metals and ferrous metals. Since 2006 the CSIR has been contracted by the Department of Science and Technology (DST) to lead the Light Metals Development Network (LMDN), with an R&D focus on aluminium and titanium.

Soon after this, the AMTS established a Composites Interest Group, which identified R&D needs in collaboration with industry players. This resulted in the first R&D projects being commissioned by the AMTS in the course of 2006.

2. Key trends and drivers in the automotive and aerospace industries

Technologically demanding industries, such as the aeronautical and automotive sectors, have over the past decade increased their demand for lighter, stronger and smarter materials and structures. In the automotive industry, the main development drivers include enhanced safety, reduced emissions and fuel consumption, and increasingly sophisticated consumer demand. It is important to note that with the exception of customer demand, the key drivers are related to government legislation – this has driven the rapid development and market introduction of innovations such as catalytic converters and more efficient engines.

The need to reduce fuel consumption and emissions has sparked intense interest in light weight vehicle construction. Indeed, the amount of aluminium used in European cars has increased from less than 50 kg on average in 1980 to well over 130 kg in 2005 (Figure 1).

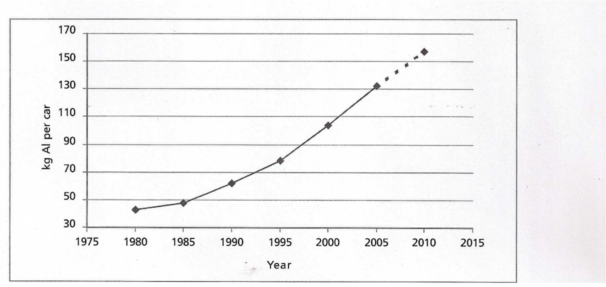


Figure 1: Evolution of Al content in European cars (European Aluminium Association, 2007).

Despite these efforts towards lightweighting, the average weight of European vehicles has actually ***increased*** dramatically, as a result of increasingly stringent legislative and customer requirements (Figure 2).

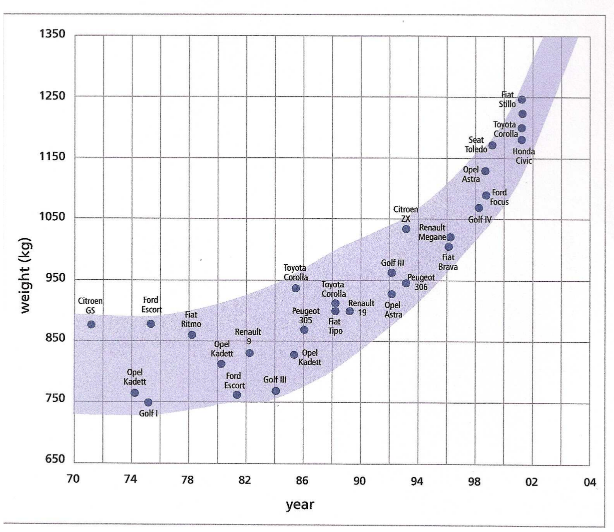


Figure 2 : Vehicle weight evolution in compact class (European Aluminium Association, 2007).

In the aerospace industry, the reduction of aircraft weight is even more important than in the automotive industry to reduce fuel consumption and increase payload. Consequently, aluminium has for many years been the standard material of construction for much of the airframe.

The social push for lighter and more economic vehicles has also led to the increasing use of composite materials in the automotive industry. Another important driver is the need for environmentally sustainable vehicles that are safe, attractive and economical to operate.

The benefits of using natural fibre composites result from the fact that they are made from a renewable and sustainable plant fibre source, they release no net carbon dioxide, are 40% lighter than fiberglass, and their production consumes one-fifth the energy of fiberglass production (Suddell 2005).

Germany has established leadership in the use of using natural fibre composites. The German auto manufacturers, Mercedes, BMW, Audi, and Volkswagen, have taken the initiative to introduce natural fibre composites for interior and exterior applications. The first commercial example was the inner door panel for the 1999 S-Class Mercedes-Benz, composed of 35% Baypreg F semi-rigid (PUR) elastomer from Bayer and 65% of a blend of flax, hemp and sisal. Flax, hemp, sisal, wool and other natural fibres are also used to make Mercedes-Benz S-Class components (Figure 3).

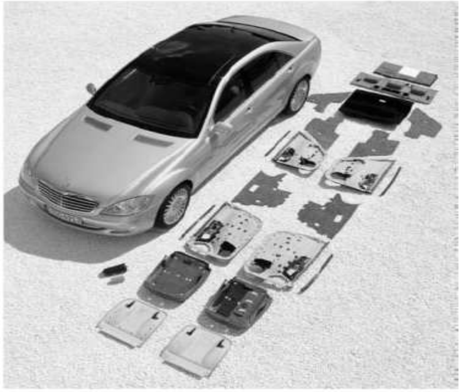


Figure 3: Mercedes S class automotive components made from different bio-fibre reinforced composites.

Two-thirds of all bio-fibres consumed in the automotive industry within Europe take place in Germany where car manufacturers are aiming to make every component of their vehicles either recyclable or biodegradable.

Statistics suggest that the total application of bio-fibres in the European automotive sector could rise to more than 100 000 t by 2010 [Karus 2004]

China and India have recently emerged as major global growth markets, with average annual GDP growth rates of around 11% and 9%, respectively. The huge demand for commodity materials in these economies, as well as the emerging indications that global production of resources such as fossil fuels has reached a peak, has resulted in an unprecedented explosion in commodity prices (Figure 4).

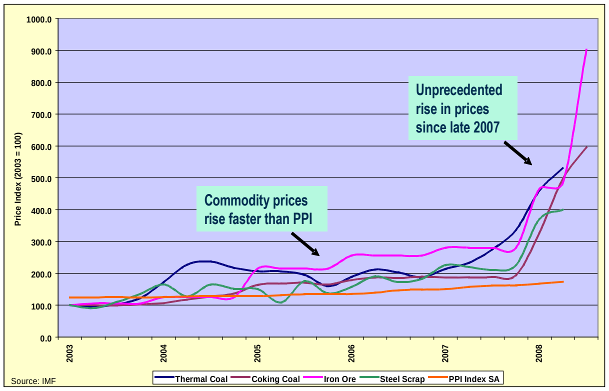


Figure 4: Commodity price trends (LHA, 2008).

Against the background of these macro-trends, there is an increased urgency on the part of the automotive and aerospace industries to accelerate the use of light weight construction and environmentally-friendly materials and manufacturing processes. Some of the related technology trends include multi-materials construction, alternative production technologies to utilise common platforms and reduce part counts, and R&D of alternative propulsion technologies such as bio-fuels, electric and hybrid vehicles, and fuel cells.

These trends have also stimulated R&D efforts in the fields of alternative light materials, such as magnesium and titanium, as well as advanced composites. The matching of material properties with application requirements is of particular importance in this regard. An example is the trend towards lighter carbon fibre composite airframe structures in commercial aircraft, which requires the increased use of titanium for structural components rather than traditional aluminium, for reasons of corrosion compatibility.

In this regard, manufacturing processes such as near-net shaping, forming of high integrity thin-walled structures and high performance machining, have also received serious attention.

In summary, it is expected that the automotive industry and to a lesser extent the aerospace industry, will experience a structural shift over the next 10-15 years towards new propulsion and vehicle construction technologies.

3. South African position and ability to respond

South Africa is a resource-rich country, but has battled to translate this potential advantage into a large downstream manufacturing sector. For example, the automotive industry is the largest advanced manufacturing sector in South Africa but is very small in global terms, representing only 0,8% of the world market. Similarly, the aerospace industry in South Africa is very small. This lack of established capacity and capability limits South Africa's ability to respond to the above-mentioned market trends.

Nevertheless, there are a few established manufacturing industry clusters that are internationally competitive. These include automotive leather, the aluminium industry (with a fully established value chain from the production of primary and secondary aluminium through to final product), the stainless steel industry (from primary stainless steel to finished product such as catalytic converters), synfuel technology spearheaded by Sasol and niche aerospace manufacturing such as avionics and internal fittings.

Also, significant public sector initiatives exist to stimulate these industries, such as:

- Motor Industry Development Programme (MIDP)
- Aerospace Industry Support Initiative (AISI)
- Advanced Manufacturing Technology Strategy (AMTS)
- Advanced Metals Initiative (AMI).

These established industry clusters and national initiatives could provide a platform for South Africa to develop certain niche competencies. As shown in Figure 5 below, South Africa's ability to play a major international role is limited in areas such as engine and power train, electronics and fuel cells.

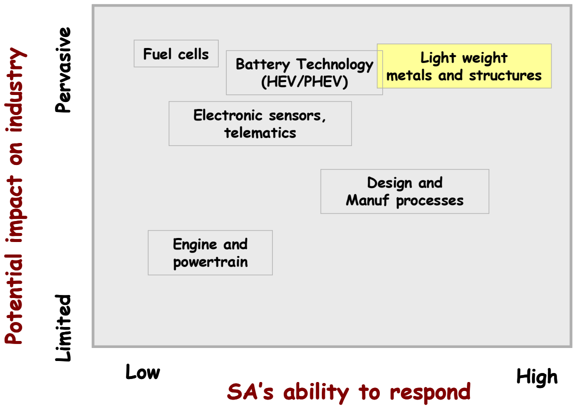


Figure 5: SA's ability to respond to major global technology trends.

However, the country is considered to be relatively well-positioned to develop competencies in light weight structures and materials, such as aluminum, magnesium, titanium, and natural fibre composite structures. This is also one of the most attractive sectors since it cuts across the automotive and aerospace industries, and will remain one of the key enabling technologies for these industries into the future.

4. Materials development projects at CSIR

Two examples of flagship projects conducted by the CSIR and its partners in fields of advanced materials, are described here.

4.1 Semi-solid casting of aluminium for high integrity lightweight components

A derivative of the semi-solid metal (SSM) technology was developed by a CSIR team in a project funded by the Innovation Fund. This resulted in the patenting of a new rheocasting technology and its associated equipment. An industrial prototype machine based on the CSIR SSM technology, was developed and built (see Figure 6).

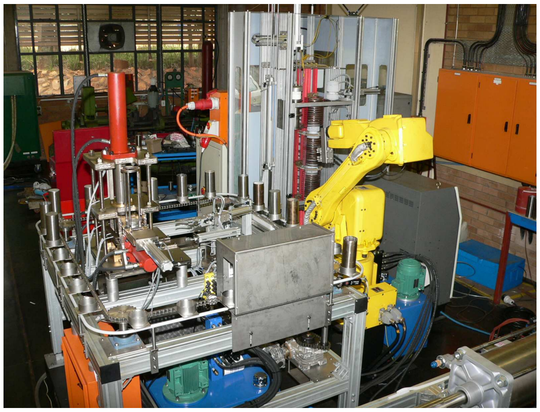
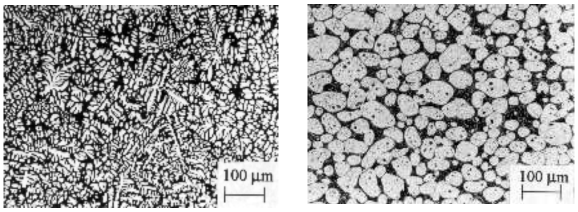


Figure 6 : The current CSIR rheocasting industrial prototype machine.

A semi-solid metal is in a thixotropic state, which is suitable for both casting and forging operations. Thixotropy is a special property of a gel that temporarily becomes liquid when sheared and reverts to a gel when static. For a metal to become thixotropic, it must be heated to a temperature where it becomes semi-solid and has a globular microstructure (Figure 7b) instead of a dendritic structure (Figure 7a). If these conditions are fulfilled, the metal slurry can be formed in a die by a high pressure die casting (HPDC) machine.



(a) **(b)**

Figure 7 : (a) Dendrite microstructure typical of liquid castings **(b)** globular structure typical of a semi-solid metal casting.

There are two versions of SSM technology that can produce metal slurries with desirable globular structure at a semi-solid casting temperature, namely thixocasting and rheocasting. Thixocasting is a two-step process. In the first step, a continuous casting operation, upgraded with a stirring device, is used to produce solidified metal with a non-dendritic structure. Rods with diameters from 75 mm to 150 mm are cast. During the second step rods are cut from billets and then heated in an induction furnace to the desired semi-solid temperature. A big disadvantage of the thixocasting process is that the scrap and returns (unused material) cannot be recycled on site.

Rheocasting is a one-step process. The molten metal is treated by cooling or by cooling/stirring from liquid to a semi solid temperature to produce a slurry with the globular shape of the solid phase followed by direct injection into a die. The big advantage of rheocasting compared with thixocasting is that the slurry can be made on demand and ‘in-house’. The chemical composition of the cast metal can also be modified and tailored to meet the quality and property specifications of the components. Scrap and other used metal can be directly re-melted in the rheocasting machine, which contributes to the lower production cost of rheocastings and hence growing interest of research centres and industry (Ivanchev et al. 2008).

The main technological advantages of the SSM forming process are as follows: the production of parts with close to the desired final shape; excellent surface finishing; good mechanical properties; it allows for the casting of a wide range of metals including high-strength wrought alloys; the production of thin-walled components; different heat treatments are possible; welding by laser in an inert gas atmosphere and the dies used to form the metal parts have a relatively long life. Table 1 lists typical automotive components suitable for forming by SSM (Ivanchev et al. 2008).

Table 1: Automotive components suitable for SSM casting

Car unit	Component
Brake system	Brake calipers, master cylinder
Fuel supply system	Fuel rails, petrol collectors, diesel engine pump
Engine and suspension	Engine block, suspension arms, belt cover, pulleys, pistons
Steering system	Power-steering valve box, clutch cylinder, wheels

More recent research at the CSIR has led to deeper understanding of heat treatment processes for semi-solid cast aluminium alloy A356 (Möller 2007, 2008) and segregation effects occurring in the alloy during SSM processing (Govender 2008). Research is also being done on utilising high strength aluminium casting alloys, such as A201, to cast components for aerospace application *via* the SSM route (Masuku 2008). With a view on fabrication using SSM cast parts, research has also been performed on laser welding of these alloys (Kunene 2008).

The CSIR rheocasting technology has since been patented in South Africa, the USA, China and Mexico and the patent has been validated in eight European countries.

From early discussions with parties interested in commercialising the CSIR technology, it became clear that the viability of the technology would have to be proven on industrial pilot scale before serious commercial negotiations could be successful. Subsequently, trials were run at an industrial foundry, Pressure Die Castings (Pty) Ltd, using an automotive part to demonstrate that the technology would be feasible in an industrial environment. While good progress was made during these trials and experience was gained, the trial sessions were too short to address all the aspects and eliminate problems. Therefore, it was decided to establish an HPDC cell on-site at the CSIR for the full industrialisation of the technology. This has since been done and the cell was commissioned during 2008. The industrialisation process should be completed by April 2009.

4.2 Natural fibre-based composites

In recent years, the CSIR has developed a strong capability in fibre-based composites, with a special focus on the use of natural fibres. Two technology platforms have been developed and merged in this time, namely fibre processing through the nonwoven route, and the science and technology of composite materials. This has provided an R&D capability to develop and test fibre-based composite materials and products for new applications in a variety of industry sectors, with a focus on automotive and aerospace.

The advantages of using natural fibres in composites arise from their high specific strength, low cost, weight reduction and renewable nature. Currently, the CSIR is concerned with the development of natural fibre based composites for automotive and aerospace applications.

One component of the research programme deals with the fabrication of flax and kenaf nonwoven reinforced polypropylene (PP) composites for semi-load bearing applications in the automotive sector. The advantages of using polypropylene stem from its low processing temperature, which is essential because of low thermal stability of natural fibres, and the good ratio between properties and cost offered by this polymer.

Plant fibres of the type used in this research are hydrophilic in nature as they are derived from lignocellulose, which contain strongly polarised hydroxyl groups. These fibres, therefore, are inherently incompatible with hydrophobic thermoplastics, such as polypropylene. Therefore, it is imperative that natural fibres should be subjected to chemical modification to increase the compatibility and adhesion between fibre and matrix (John 2008a). This adhesion in the so-called interfacial zone determines to a large extent the mechanical properties of the composite.

Different chemical modification strategies were adopted as part of the CSIR research, all with a view to increase the interfacial adhesion between the fibre and matrix.

Preliminary results have shown that incorporation of flax and kenaf nonwovens in a polypropylene matrix results in improved strength and modulus (Figure 8).

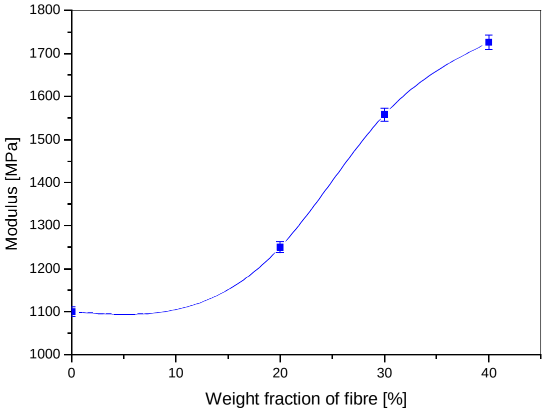
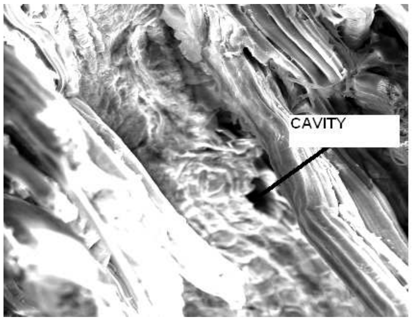


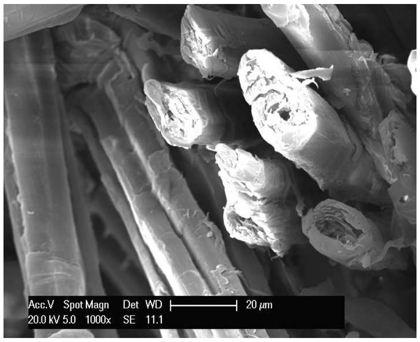
Figure 8 : Variation of modulus of flax-PP composites.

Chemical modification through the use of biological coupling agents resulted in improved mechanical properties. An additional advantage of this modification was that it preserved the biodegradable nature of the fibres. The viscoelastic characteristics and thermal stability were also found to increase. (John 2008b)

Scanning electron micrographs revealed the better interfacial adhesion in the treated composites with the presence of short broken fibres projecting out of the matrix, as seen in Figure 9 (John 2008c).

(a) Untreated





(b) Treated

Figure 9: Scanning electron micrograph of **(a)** untreated and **(b)** treated flax-PP composites.

Another aspect of the research programme addresses the challenges facing the aerospace industry in the next decade to fully realise the performance benefits of composite materials while dramatically lowering production and operating cost with a minimal impact on the environment.

The focus is on the development of composites based on natural fibres and/or bio-composites for use in secondary structures in cabin and cargo areas.

Airframe structures need to fulfill extreme requirements during a very long product life. The materials that are currently in use are metal alloys, carbon fibre composites and hybrid laminates. The drawbacks of these materials concern their high density, cost and poor impact behaviour.

The advantages of using natural fibre composites in aircraft are:

- Reduced fuel consumption and lower emissions due to lower weight
- High specific strength and stiffness enabling the design of complex shapes that are more aerodynamically efficient than metals
- Reduced corrosion problems, potentially reducing the airline maintenance cost
- Biodegradability.

A key challenge of the research involves achieving the stringent FST (flame, smoke and toxicity) standards. Preliminary experiments on flame retardant treatments of plant fibres have been encouraging. The overall conclusion that is reached through the research is that natural fibre-based composite structures are promising candidates for aerospace applications in the near future.

In a recent development Airbus, the world's leading commercial aircraft manufacturer, and the CSIR have formed a partnership to jointly research the application of natural fibre-based materials on new-generation eco-friendly aircraft.

In particular, the research will look into the potential application of natural fibres such as hemp, flax and kenaf in the fabrication of aircraft interior components such as side-wall and ceiling panels, and other less load-bearing parts.

The first phase of the project is concerned with developing new sandwiched panels made from natural fibre reinforced thermoset composites, which will replace the synthetic panels currently in use. The second phase of the project will utilise bio-polymers from natural renewable materials.

5. Networking and collaboration

In the LMDN, the CSIR forms the hub with research groups at universities and other science councils forming the different nodes. Under the leadership of the CSIR, the research activities at the nodes have been coordinated and aligned. This model facilitates optimising the development and utilisation of South Africa's limited human resource capacity and expertise. It also maximises the benefit of investment in expensive research equipment by avoiding duplication wherever possible and ensuring access for researchers to unique equipment and facilities in the network.

Local and international collaborators are involved and alliances are also being built with private sector stakeholders. Forums, such as the AMTS Casting Technology Consortium and the AMTS Composites Interest Group, have been playing an important role towards achieving this.

The Airbus project referred to earlier involves a consortium called Natural Fibre Reinforced Bio-composites (NATFIBIO), which is led by the CSIR. The Nelson Mandela Metropolitan University and the University of Cape Town's Centre for Research in Computational and Applied Mechanics are also involved. The DST provides funding for the project *via* the Advanced Manufacturing Technology Strategy.

Structures such as these provide opportunities for industry needs to be surfaced and for research programmes to be aligned with these real-world needs. Maintaining healthy relations with the automotive, aerospace, metals and plastics industry sectors while developing and executing the R&D programmes, also supports successful transfer of technology and commercialisation of products and processes.

6. Human capacity development

In support of the above-mentioned national R&D initiatives, various programmes have been implemented to develop a pipeline of future employees for these initiatives and for industry.

Bursaries for postgraduate studies in related disciplines at collaborating universities are funded by the R&D initiatives. The CSIR offers studentships for studies towards Master's or doctorate degrees aligned with the light metals and composites research projects. After successful completion of their studies such students are employable by the R&D institutions or by industry.
Opportunities also exist for experiential training of students at CSIR as part of obtaining their first degree.

Since 2006, 30 bursaries and studentships as well as three postdoctoral fellowships have been awarded by the LMDN and the AMTS composites initiative. The postdoctoral placements have strengthened the research teams and also added supervisory capacity for postgraduate students.

Figure 10 gives a graphical picture of the profile of postgraduate qualifications supported by the LMDN and the composites R&D programme.

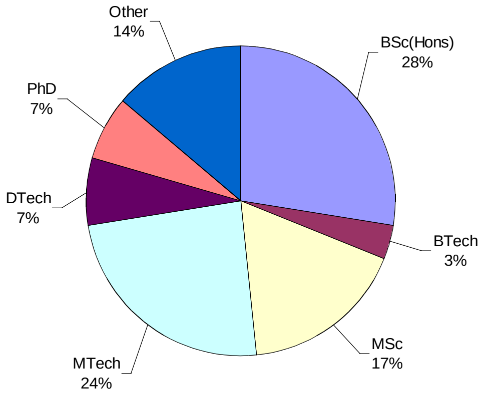


Figure 10: Distribution of postgraduate qualifications supported by the LMDN and composites R&D.

Full-time staff at the CSIR and participating universities also have the opportunity to improve their formal qualifications, based on the research done under these initiatives.

7. Impact

The R&D programmes described here address key drivers of industry change, including the need for high performance lightweight materials, greater fuel efficiency, environmental protection through recycling and biodegradability, and new cost effective processing routes. Over a period of time, the impact of the programmes will, therefore, be reflected in improved industry competitiveness, protection of the environment, and contribution to national human resource development.

There are already signs of achieving impact in these ways. For example, the automotive industry has expressed interest in applying the CSIR rheocasting technology locally for the benefit of the industry, and this sentiment has been endorsed by the **dti**. Discussions have also been initiated with the French aerospace company Snecma on possible application of this technology .

In addition, well qualified and highly skilled individuals are being developed through these R&D programmes, and have a choice to either make a career of R&D or to invest their expertise in the South African industry. Both these options will be beneficial for the local industry.

8. Conclusions

Exciting and highly relevant R&D programmes on advanced materials, such as those concerned with light metals and advanced composites, are underway at the CSIR. External partners are involved and the work is financially supported by the DST.

The programmes provide unique opportunities for human resource development and improving industry development and competitiveness. Supported by the national initiatives led by the CSIR, they have already started to make a contribution towards socio-economic development.

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Endnote

The authors wish to acknowledge the funding support provided by the DST and the AMTS. We also express our appreciation to our R&D collaborators at the various universities and to the CSIR R&D teams who are continuing to ensure we produce outcomes that will have lasting impact in South Africa.