South Africa’s Space Programme of the mid-1980s to mid-1990s: Driver towards a South African Titanium Industry

Dr Willie du Preez
Manager: Metals and Metals Processes
Materials Science and Manufacturing

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Outline of presentation

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  • Progress on R&D and technology platforms

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Introduction
• The South African Space Programme of the mid ’80s to mid ’90s resulted in fascinating achievements in mastering and applying specialised technologies

• Individuals who participated in this high-tech programme later contributed strongly in other demanding industry sectors

• Experience gained through developing technologies for processing the Ti-6Al-4V alloy to produce satellite components prepared me for a leading role in today’s South African Titanium Strategy

• The talk will show how this strategy supports the current South African Space Programme
Properties of Titanium

- Titanium is the 4th most-abundant structural metal on earth.
- The density of titanium is only about 60% of that of steel.
- The tensile strength compares favourably to stainless steels, iron-base superalloys and cobalt-base alloys: its specific strength is much higher.
- The commercial alloys of titanium are useful to temperatures of about 540°C to 600°C.
- Titanium is exceptionally corrosion resistant - exceeds that of stainless steel and has outstanding corrosion resistance in the human body and in seawater.
Drivers of the International Titanium Industry
Drivers of the International Titanium Industry

Cold War:
- Titanium in military aircraft (USA)
- Titanium in submarines (USSR)

Space Missions:
- Titanium in satellites
- Titanium in launch vehicles

Commercial Aircraft:
- From less than 4% in Boeing 747 to >17% in Boeing 787
- Similar increase for Airbus
- Growth of >50% expected over the next decade
Cold War: Titanium in Military Aircraft of the USA

The SR-71 Blackbird

Designed & built in 1959 - 1963

Fastest airplane ever:
Mach 3.2 (3700 km/h)
at 80 000 ft ~ 24 km
New York - Londen: 1h 55min

Fuselage skin temperature:
200º - 370ºC
Needed to be lightweight

Constructed for 90%+ from Titanium alloys

50 million pounds Ti used during development
67 tonnes per SR-71
SR-71 Performance

**SR-71 RECORD SPEED RUNS**

NEW YORK - LONDON (SEPT. 1, 1974)

NEW YORK TO LONDON
TIME: 1:55:32
DISTANCE: 3470 MILES (3014 NM)
AVERAGE SPEED: 1817 MPH (1578 KNOTS)

LONDON - LOS ANGELES (SEPT. 13, 1974)

LONDON TO LOS ANGELES
TIME: 3:47:39
DISTANCE: 5463 MILES (4745 NM)
AVERAGE SPEED: 1438 MPH (1249 KNOTS)

2300 km/h

2907 km/h
Titanium Content per Airframe

(J. Monahan, ITA Conference, 2006)
Titanium in South Africa’s Space Programme of the mid 1980s to mid 1990s
Developing Satellite Components: The Challenges

- Titanium (Ti-6Al-4V) in high pressure vessels on satellites
- User specifications were provided
- Manufacturing processes had to be developed
- Manufacturing facilities and equipment had to be established
- Products had to be qualified for use
- Test and evaluation facilities had to be established
Technology Development

Technologies established:
- Component & system design
- Finite element based analysis
- Die design & manufacture
- Forging
- Superplastic forming
- Machining
- Electron beam welding
- Laser welding
- Non-destructive testing
  (X-Ray microfocus imaging)
Commercialised Satellite Fuel Tanks from Ti-6Al-4V
Spin-off Application: Locally Developed Hip Stem

Key technologies utilised:
Engineering design & analysis
Die design & manufacture
Forging
Machining
Hydroxyapatite coating

Towards a South African Titanium Industry
Strategic Highlights

1999: National Research and Technology Foresight Project recommends Ti metal and TiO₂ production from South African raw materials

2002: Publication of the Integrated Manufacturing Strategy by the dti and the National Research and Development Strategy by the DST

2002/3: Development and approval of the Advanced Manufacturing Technology Strategy (AMTS)

2002-5: Establishment of the Advanced Metals Initiative as implementation initiative
  - 4 Pillars: Light Metals Development Network (LMDN), PMDN, NMDN, F&BMDN

2006: DST contracted CSIR to lead the LMDN
  - Focus on Titanium and Aluminium

2003-5: Development of the SA Aerospace Strategy

2009: CSIR contracted by DST to establish the South African Titanium Centre of Competence
The South African Innovation Opportunity

- Significant Ti ore reserves
- Raw material

- Primary metal and mill product technologies
- Processes & technologies

- Component manufacturing technologies

- Existing markets:
  - Aerospace
  - Automotive
  - Medical
  - Recreational
  - Industrial (e.g. Power plants)
  - Chemical

The Titanium Centre of Competence integrates and coordinates R&D and commercialisation across the value chain.

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Titanium Centre of Competence
Developing and Commercialising the Technology Building Blocks of the South African Titanium Industry

Industrialisation & Commercialisation

Market Development

Supplier Development

Technology Development

- Physical Metallurgy of Titanium: UCT, UP
- Simulation and Modelling:
  - ULim(Ab Initio), CSIR(FEM, ProCast, Ab Initio), UCT(FEM, Proc. Mod.), CPUT(Weld Sim)

R&D Platforms

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Titanium Centre of Competence Collaborators

**International**

**R&D Institutions:**
- NIMS (Japan)
- Univ California Davis (USA)
- ESRF (France)
- Fraunhofer Inst (Germany)
- Univ of Birmingham (UK)
- Univ of Plymouth (UK)
- ALD (Germany)

**Companies:**
- Snecma (France)
- Airbus (France)
- Rolls-Royce (Canada)
- Boeing (USA)
Primary Titanium Production

- First Titanium powder produced
- Demonstration of continuous processes
- Pilot plant in 2011
Investment Casting of Titanium Alloys

- Only a few players in the world can cast Titanium successfully on commercial scale

- They handle this as proprietary knowledge and do not publish detail

- CSIR had to develop the key processes in the casting process chain

- We upgraded facilities used successfully in the 1990s for casting turbine blades in Nickel-based superalloys, to enable us to investment cast Titanium alloys
Investment Casting of Titanium Alloys

- Developed and packaged the Titanium mouldmaking and crucible melting processes

- Developed and packaged the chemical milling process

- Casting an aerospace demonstrator part
Commercialisation of Investment Casting of Titanium

- Find industrial/commercial partner
- Decide on technology transfer to existing operation or to incubate new enterprise
- Proceed with industrialisation and commercialisation
Titanium Powder Processing

• Our primary Titanium metal production process delivers a Titanium powder

• More affordable Titanium powder will unlock a much broader market for Titanium products produced from powder

• Therefore we have been developing a Titanium powder processing competence since 2006

• Through strong support from the DST we have been able to acquire essential equipment
Titanium Powder Processing

- Establishment of metal injection moulding process
- Development of own binder

- Patent on novel Ti-Mg alloys via direct reduction of TiO$_2$

- Compaction and sintering of powder produced through the CSIR process

www.csir.co.za
AMTS High Performance Machining (HPM) of Light Metals with an Emphasis on Titanium and Selected Alloys

- **Main Objectives**
  - Build world class competence in HPM of light metals
  - Increase competitiveness of SA firms to become part of the global supply chain of high added value components

- **Research and Development Focus Areas**
  - Consolidation of high performance machining knowledge base for light metals
  - High performance machining of Ti and Ti alloys in raw or near net shape forms
  - High performance machining of integral Ti parts
  - Optimisation technologies for machined Ti components

- **Consortium Members**
  - Stellenbosch University
  - University of Johannesburg
  - University of Cape Town
  - Fraunhofer Institute for Machine Tools and Forming Technologies
Additive Manufacturing of Titanium

Direct laser sintering of Titanium to produce medical implants

Images courtesy Prof Deon de Beer, VUT
Friction Stir Welding of Titanium
Relevance for the Current SA Space Programme
The Titanium Centre of Competence provides access to 60 - 70 local researchers and technologists, linked to international experts.

A student pipeline has been established, with up to 30 postgraduate students involved in the programme at any point in time.

Titanium products and metal processing technologies for the manufacturing needs of the Space Programme can be developed locally.
Conclusions
Conclusions

• Titanium and its alloys, which are key for many components in satellites and launch vehicles, will be locally available in future

• Through sustained investment of the Department of Science and Technology, the CSIR, other science councils and universities, a strong local resource and expertise base on titanium and its processing has been established

• The Titanium Centre of Competence is integrating and coordinating R&D and commercialisation across the titanium value chain and is well positioned to serve the South African Space Programme
Thank You