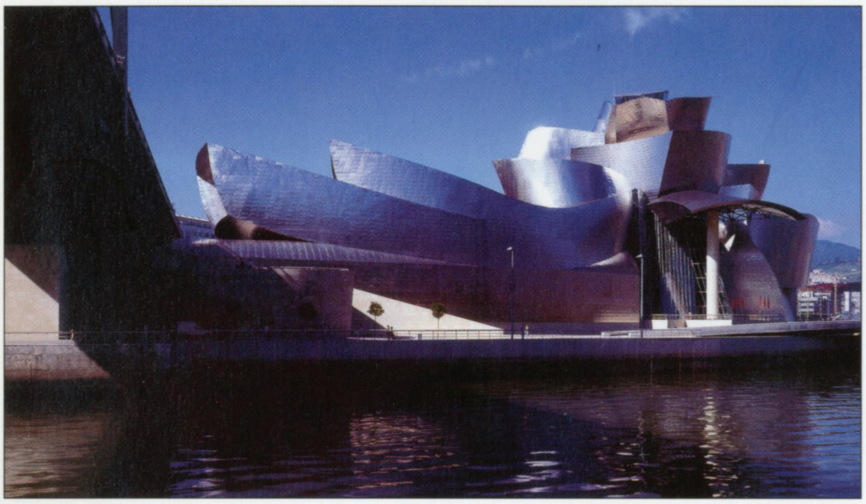
Cambridge
material eyes

Autumn 1998 Issue 6

Technological Breakthrough



©FMGB "Provenance: Guggenheim Museum, Bilbao"

The Guggenheim building in Bilbao pictured here, is a fantastic monument to the aesthetic qualities of titanium. If the work currently being carried out under the leadership of Professor Derek Fray is successfully exploited in the future, then titanium is a material which could well become much more common place for everyday usage. A new process of extracting titanium from its source mineral, rutile, has been discovered, which has the potential to reduce the cost of the metal by 40%, giving it a price equivalent to stainless steel. Professor Fray explains:
"TiO_2, (rutile) from which Ti is extracted is cheap and readily available (actually it is used in the paper and paint industries because of its white colour). However the process of extraction of titanium from TiO_2 is complex and lengthy. It takes about a week to produce 4 tonnes of the metal, hence its high price. Chlorine and coke are used to remove the iron impurities from the rutile at high temperature, and the $TiCl_4$ which is produced then has to be reduced by reacting it at high temperature with magnesium. This is known as the Kroll process. The Ti sponge which emerges from this process has to be dug out of the furnace manually with pneumatic drills. The price per tonne at this stage is around £8,000 and that increases to £30, 000 after all the machining processes required to make the end product."

Many methods have been investigated to improve the production of titanium on a laboratory scale, but up until now, none have shown the opportunity for dramatic cost reduction. Recently, however, Dr. George Chen and Professor Derek Fray discovered, in one of the Department's laboratories, that pellets of titanium dioxide could be reduced in a fused salt to porous titanium metal at around 950°C within a few hours. Suprisingly, the product consisted of 12μm particles of titanium metal, which were lightly sintered together.

"This new process has many potential advantages," comments Prof. Fray. "It takes a few hours of processing time instead of a week, and the product formed may be suitable for powder metallurgical processing which can offer substantial savings in fabrication costs. No-one has ever reduced an oxide in this way before, and the process should be applicable to the reduction of many other oxides, such as zirconium and the rare earths."

Enquiries to: Prof Derek Fray;
T: 01223 334306; email:djf25@hermes.cam.ac.uk

Editorial

Part of the Department's strategy for the 2000's is the strengthening of research and teaching in the field of Medical Materials. It is only in this way that we can help to meet the ever-growing expectations for quality of life in our ageing population. The Department is active in the area of pharmaceutical materials, and prosthetic devices, especially with regard to their wear characteristics and coatings technology. However, a major development is the decision to establish a Professorship of Medical Materials which will be based in this Department. The new activity will build on current research to form an Institute of BioMedical Materials and will link with related activities elsewhere in the University. The Institute will focus on four key areas: *Prosthetics*, where there is not only a need for better materials for implants, but for a better understanding of interfaces with living tissue. *Medical Devices*, which assist in various treatments, also require new materials with specially tailored properties. *Drug Delivery Systems*, which make demands for materials to release a drug according to a prescribed programme. Finally, there is the exciting new field of *Tissue Engineering* where both physical and life sciences are combining to make replacement body parts, where it is no longer clear whether the material being created is artificial or living. As we meet these new challenges, the Department cannot help but change, indeed, (paraphrasing A.P. Hartley). *The future is a foreign country, they do things differently there.*

Contents

Virtual Work

Visitors to the Department and regular readers of 'Material Eyes' will have noticed the increasing emphasis within the Department on computer modelling. In the Rolls-Royce University Technology Centre (UTC), this process is being taken to its limits, with the goal of setting up a "virtual factory" for various types of manufacturing processes. Roger Reed, Research Director of the UTC explains: "Typically, Rolls-Royce design components with metals. The major manufacturing processes involved include welding, forging/heat treatment, thermal spraying, machining and casting. All these processes need optimising for best results and to reduce wastage. Traditionally, a best practice approach has been achieved empirically, but often the costs involved in trials mean that components and processes have not been fully optimised. If, however, the behaviour of materials can be quantified and understood, then processes can be optimised using computer models. We start by looking at how grain structure evolves, for instance, and then seeing how processing parameters need to be chosen to influence the materials performance."

For example, within the aeroengine industry, electron beam welding remains the preferred joining technique for the joining of compressor assemblies. One of the research areas in the Rolls-Royce UTC at present is to characterise the stresses built up as a result of this welding process and to understand how distortion arises.

Computer simulation of the evolution of grain structure in a single crystal casting. Turbines blades are cast using a spiral starter. The orange colour shows the growth of a single crystal. by Dr P. Carter and Dr C. Gandin

An understanding of the thermo-mechanical response of the material is required to show how the process parameters of welding will affect the levels of stress induced so as to avoid excessive distortion.

"We are trying to make our models as simple as possible, but not too simple. The challenge is to have good constitutive equations, and to have good data to validate our approaches against."

Apart from optimisation of processes, Roger Reed points out that the production of such computer models can be beneficial in improving communications between the designers and manufacturing engineers. "By using our models, designers can understand how stresses have evolved in components, and the manufacturing engineers can see how their processes may cause difficulties. Sometimes the requirements of the designers are beyond what is possible in terms of the manufacturing process, and this is good to know. I see improved communications between different groups in industry as a positive benefit of our modelling approach."

Further information from
Dr Roger Reed T: 01223 334320, e-mail rcr10@cus.cam.ac.uk

Golden Years

Materials Science is nowadays such an established subject area in many universities across the world, that people forget that its existence is relatively new. The first metallurgical research laboratory in Cambridge was set up in 1920 as a result of a grant of £5,500 from the Worshipful Company of Goldsmiths. Prior to that, the subject had been studied by individuals in their own laboratories, which in Cambridge were originally college-based. Thus it was that C.T. Heycock and F.H. Neville conducted the first ever comprehensive study of the equilibrium diagram of a non-ferrous alloy system (Cu-Sn) in 1903, in their laboratory in Sidney Sussex. In 1908 the Worshipful Company of Goldsmiths endowed a Readership in Metallurgy.

Over 300 children and parents took part in 'hands-on' experiments during a one day event which the Department hosted for National Science Week.

Elected to this post, Heycock then petitioned the company to further equip some rooms in the Department of Chemistry to continue his work.

No doubt Heycock was encouraged in his plans to set up a University-based laboratory, not only by the interest shown in his work but also by the fact that many of his research papers and photographic negatives were destroyed in College following a particularly riotous bumps supper in 1910. Sidney students were not allowed to enrol for Heycock's metallurgy courses again until 1914, following that incident!

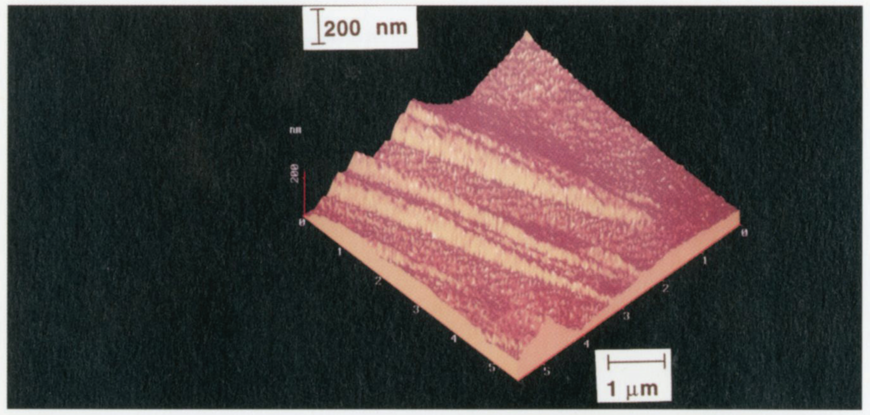
The laboratory that was opened in 1920, as an extension to the Chemistry Department on Pembroke street was named the Goldsmiths' Metallurgical Laboratory, and it is still part of the Department today. In fact it served as the main accommodation for the department for the following twenty five years without further extension. The first Goldsmiths' Chair of Metallurgy was endowed in 1932, when it was held by R.S. Hutton, until 1945. Since then there have been a further six holders of the Goldsmiths' Chair with Professor Colin Humphreys being the most recent.

The first Part II class graduated in 1937 (four students) and the 'Metallurgy hut', later to become a bike shed until being transformed into the Rolls Royce University Technology Centre, was built as the first extension to the premises in 1946.

The seventy-fifth anniversary of the opening of the Goldsmiths' Laboratory was celebrated with lectures, tours and social events for alumni in 1995, and at that time Professor Colin Humpheys wrote "I believe that the Prime Warden of the Goldsmiths' Company who opened the Laboratory in 1920, Mr Montagu Tabor, would be astonished to see how the Goldsmiths' original investment has grown. The Department now occupies all or part of five buildings in central Cambridge. We teach Materials Science to over three hundred undergraduates each year. We have 150 research students and over 50 post-doctoral research fellows."

Of course this success has led to the search for yet more accommodation, and the Department is now planning its most major move ever, to a green field site one mile away to the west. Once again, the Goldsmiths have provided a most generous donation, and once again they move first.

Shear Deduction



A direct observation of the displacement of atoms due to the formation of bainite, made by atomic force microscopy.

Harry Bhadeshia was elected a Fellow of the Royal Society earlier this year in recognition of his contribution towards the understanding of phase transformations in steels. He is quick to point out that this honour is the result of the untiring efforts of the many research students with whom he has had the pleasure of working, over the last twenty years.

When Harry completed his PhD in 1979 there was a lot of discussion about how one phase that is observed in steels, bainite, actually forms. He explains: "Bainite forms somewhere between the temperature at which martensite forms and that at which pearlite forms. The formation of pearlite clearly involves lots of diffusion, whereas martensitic transformation is completely diffusionless. These two reactions are clear-cut, one being displacive and the other diffusional. In between the two, we have bainite. Surface relief associated with bainite was first observed in the early 1950s, indicating that its formation involved shear, like martensite.

However, unlike martensite, the speed of transformation is relatively slow and it shows a temperature dependence which is characteristic of diffusional transformation. These apparent contradictions led to years of controversy. The thermodynamics which indicated that bainite was indeed the result of a diffusionless transformation was worked out in 1979. The first direct observation of the displacement of atoms due to the formation of a single plate of bainite in steel was not made until 1996 using atomic force microscopy.

Although there are still difficulties in accepting that bainite is actually formed as a result of diffusionless transformation, in Harry's view, the evidence is sufficient to allow the useful exploitation of the theory. "Photo-emission electron microscopy has been used for direct measurement of the growth of plates, which occurs at speeds much faster than diffusion. The shape change predictions have been shown to be accurate by direct observation using atomic force microscopy. The model produced for bainite also predicts the existence of other phase transformations in steels such as lower acicular ferrite in weld metal microstructures, and these have subsequently been shown to occur.

It is important to understand how the various phase transformations we observe occur, because if we can't talk about how things form, we can't do the calculations necessary to make quantitative estimates which can then be used in design." The predictions that can now be made as a result of the establishment of thermodynamic and kinetic understanding of transformations are such that new alloys with specific properties can be designed. Perhaps the most well-known of these so far is the development of a new rail steel which was reported in issue 2 of Material Eyes. We look forward to more exciting developments in the future, perhaps culminating in Harry's dream of a steel which is transparent to light. Who knows what the future will bring?

**For details contact;
Dr HKDH Bhadeshia
Tel: 01223 334301
email: hkdb@cus.cam.ac.uk**

A Fishy Story

- Profile of David Duke

When David Duke first started work as a technician in the Department, straight from school in 1964, Alan Windle had just joined Gerry Smith's group as a research student. Thirty years on, Alan Windle is a Professor, and Head of Department, while David is now Principal Technician. "I can honestly say that in all that time there has never been a day when I haven't wanted to come to work." says David, "I enjoy the company and the Department has stayed the same friendly place that it was all those years ago when I first started".

Of course there have been many changes in the last thirty years, perhaps the most obvious being the change of size of the Department, and where it is housed. David Duke helped with the move from the Goldsmith's Building to the brand new shiny Arup building in 1971. "Lion Yard was just being built and it took us a year to move everything across. Then, within a year, we moved Superconductivity back again.

David remembers the time when the class technicians had to come in every Saturday to polish the benches and metallography was a daily feature of the undergraduate training. "We had to set out new emery papers and etching solutions every day for the students, and had to cut our own polishing cloths from blazer material that we went to buy from the local gents outfitters. Final polishing was done using aluminium oxide on blazer cloths." The undergraduates also used to learn how to make up their own thermocouples, calibrating them with ice and open pots of molten lead. Health and safety inspectors must cringe at those memories.

David Duke took over as Principal Technician six years ago, when Derek Starnell retired. He describes his job as being a 'Mr Fix it' with responsibilities varying from day to day administration of the Department's 46 Assistant Staff and liaising with Estate management to looking after internal security. He has to advise on use of space within the Department, and is rightly proud of his suggestion that the new Rolls Royce technology centre could be housed in what was then an old bike shed!

The addition of a fish tank and water feature to the reception area of the Arup building is a sign of David's other passions in life. He has a large pond at home, with about 70 fish, and a menagerie of small animals and birds. His gardening interests are reflected by the flourishing plants in the roof garden of the Arup building, one of its more pleasant features, and indeed in his own office which is filled with cacti ("they don't mind neglect") as well as another beautifully kept fish tank.

Keeping fit is no problem as David cycles the four miles in from his home in Teversham, where he is Vice Chairman of the Parish Council, Primary School Governor and Chairman of the Village Social Club. He is now looking forward to his part in the future development and undoubted further expansion of the Department.

Congratulations to

- Dr Harry Bhadeshia on being elected Fellow of the Royal Society in May this year.
- Dr Mark Blamire on his appointment to a University Lectureship.
- Dr Tim Burstein on his appointment to a University Lectureship.
- Dr George Chen on winning a first prize for his poster at the European Research Conference "Molten Salts", Porquerolles, France.
- Dr Bill Clegg on his promotion to a Readership in Ceramics.
- Dr Jan Evetts on his promotion to a Personal Chair in Device Materials.
- Dr Vasant Kumar on his appointment to a Staff Fellowship in Trinity Hall.
- Robin Preston on winning the Abaqus User Group 1998 UK Students' Research Prize.
- Andrew Rayment on his promotion to Technical Officer.
- Sir John Meurig Thomas on being the first recipient of a major new American Chemistry Society Prize "Creative Award in Homogenous and Heterogeneous Catalysis".

This newsletter is written by Sue Jackson, produced by Navini Nynan and printed by:
ABS Print Services Ltd

For any feedback regarding the content of this newsletter and any alterations to your address, please get in touch with Navini Nynan at the address below or call on:
Tel 01223 334479
Fax 01223 334567

Department of Materials Science and Metallurgy
University of Cambridge
Pembroke Street
Cambridge CB2 3QZ

Visit us on:
http://www.msm.cam.ac.uk