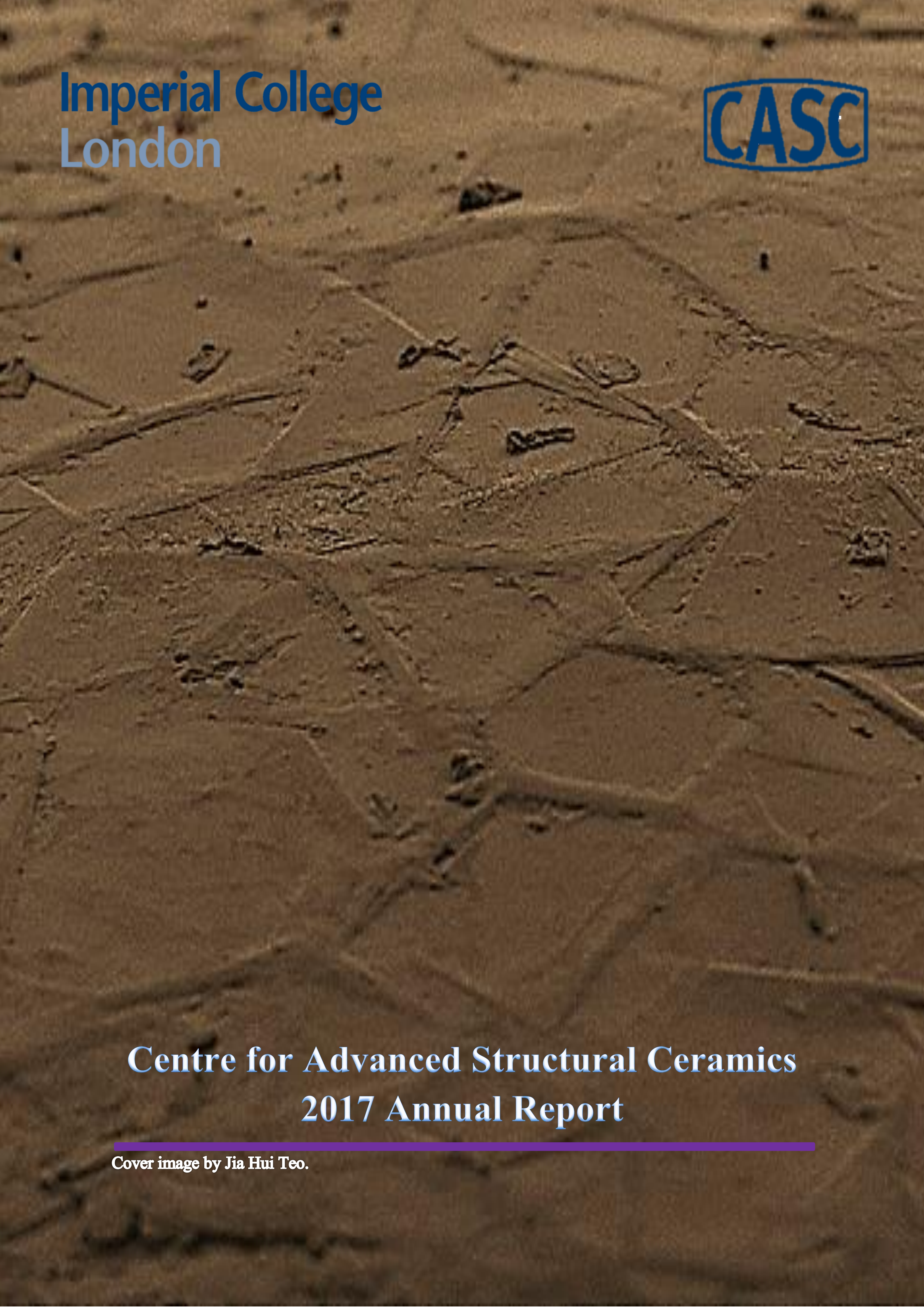
Imperial College London

CASC



Centre for Advanced Structural Ceramics
2017 Annual Report

Cover image by Jia Hui Teo.

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Introduction

CASC started running in July 2008 with EPSRC funding (£5.5M) for a five-year programme. The EPSRC funding came to an end in June 2013, but CASC continues to grow each year, establishing new industrial collaborations from abroad and in the UK, together with different research projects.

An Industrial Consortium has been set up to build on CASC's early success, enable its sustainability and continue long-term and fruitful relationships between CASC's associated academics and the UK's ceramics community.

Our main goal is to continue these relationships and grow as a ceramics centre.

Professor Eduardo Saiz

CASC Director

MANAGEMENT

CASC was initially set up by Professor Bill Lee in 2008. In 2012, he was succeeded as Director by Professor Eduardo Saiz.

Local Management Team (LMT)

The LMT is responsible for managing the centre's operations and meets monthly to oversee the pressing day-to-day issues of running the Centre. These issues include staff appointments, equipment purchase, finances and building refurbishment, but are increasingly focussed on developing the Centre national and international profile, forging industrial links and achieving financial sustainability.

The LMT is chaired by Eduardo Saiz and other members are Finn Giuliani, Luc Vandeperre, Ainara Aguadero, Stephen Skinner, Daniel Balint, Julian Jones and Garry Stakalls.

The meetings are also attended by representatives of the Postdoctoral Researchers (Dr Daniel Glymond) and PhD students (Ms Jia Hui Teo) working on projects related to structural ceramics.

Industrial Consortium Group (ICG)

A key part of CASC's sustainability is the development of a consortium of companies with interest in structural ceramics.

After the end of the EPSRC funding in 2013, an industrial consortium scheme was set up to build on CASC's early success, to enable its sustainability and to support the long-term and fruitful relationships created between CASC-associated academics and UK's industry. This was planned and presented in our first Industry Day meeting the 17th of May of 2011, where it was well received by the industry representatives and was developed by our Steering Group on July 4th 2011.

The Industrial Consortium started functioning in 2014 after the Steering Group meeting, held the 17th of January 2014.

The ICG develops the CASC Business Plan which contains the Centre's vision, objectives and an action plan to deliver such vision. It also acts as an advisory role to the Director and the Local Management Team, providing advice on:

a. The strategic research focus of the Centre.
b. The infrastructure, skills needs and links to industry and other research groups worldwide.
c. The structure and content of undergraduate and postgraduate courses provided by the Centre.

The consortium has three levels of membership with a graduated annual fee and access to CASC facilities, people and projects (table in page 4).

Diamond membership is aimed at large and multinational companies, who would like strategic advice and board-level interaction with senior academic staff at CASC. The relationship, which might include technical briefings and RAEng Industrial Fellowships, would be tailored to individual company requirements.
On the other hand, Sapphire and Ruby memberships are aimed at companies who want to collaborate with CASC on research and training.

All three levels of membership provide:

- Access to CASC equipment, at preferential rates, (including hot press, vacuum furnace, nanoindenter…) with operator and interpretations.
  The degree of access will depend on the level of membership as seen in the table below.
- Access to CASC and CASC associated academics.
- A number of free positions at CASC Summer School.
- Access to Materials, Mech. Eng. and CASC students as potential employees.
- Opportunity for secondment of industrial researchers to CASC.
- Opportunity to propose undergraduate final year research projects, at differing levels depending on membership. Projects run from October to May and descriptions of such are needed by Easter previous year.
- Opportunity to propose research projects for students on Master Courses (Advanced Materials, Biomaterials & Nuclear), at differing levels depending on membership.
  Projects run from April to September, descriptions needed by May previous year.
- Opportunity to collaborate on out-of-term and industrial placements. Interviews can take place form October onwards.
- Receiving the CASC annual report and newsletter as well as information on CASC sponsored events.
- Opportunity to propose a subject for a PhD funded by the consortium.
- To date we have 1 member signed up at Sapphire level (Morgan Advanced Materials) and 4 members at Ruby level (Asahi Glass, SAFRAN, Reaction Engines and John Crane) and we are in advanced discussions with several other companies. If you are interested in becoming a member of the CASC Industry Consortium, contact: Eduardo Saiz < e.saiz@imperial.ac.uk – 020 7594 6779> or Alba Matas Adams < a.matas-adams@imperial.ac.uk – 020 7594 2053>

	Diamond	Sapphire	Ruby
Type of membership	Strategic	Research & Training	Research & Training
Steering Group member	Yes	Yes	Yes
Equipment use **Free allowance up to** **Preferential rates**	 £10,000 Yes	 £3,000 Yes	 No Yes
Proposing MSc, BEng and MEng projects	8	2	1
Access to CV's of graduating students	Yes	Yes	Yes
Free summer school positions	10	3	1
Membership fee	£50,000+VAT	£15,000+VAT	£5,000+VAT

PEOPLE

Staff

Professor Eduardo Saiz

Eduardo has been CASC's Director since August 2012. He previously was a Staff Scientist at the Materials Sciences Division of Lawrence Berkeley National Laboratory (LBNL) and joined CASC in October 2009. Eduardo took over the role of Deputy CASC Director in July 2010.

After graduating in Physics from Cantabria University in Spain he gained a PhD in Applied Physics from the Autonoma University of Madrid, working on the processing of ceramic superconductor thick films. In 1992 he became a Fulbright postdoctoral researcher at LBNL. He has worked extensively in the area of high-temperature capillarity and interfaces between dissimilar materials, developing new approaches to study spreading and adhesion in metal-ceramic systems and this continues to be a topic of research. Another area of interest is in the development of new hierarchical, hybrid materials and coatings (metal/ceramic, polymer/ceramic) as well as complex porous ceramics. One of his objectives is to develop high-temperature composites able to perform in extremely hostile conditions and increase efficiency in the transport and generation of energy. He is also working in the fields of biomineralization and the development of new ceramic-based biomaterials to enhance the osseointegration of orthopaedic implants and support the engineering of new bone and cartilage.

Professor Bill Lee

Professor Bill Lee was the founding Director of CASC from July 2008 until August 2012 and was the principal investigator of the EPSRC award. Bill is a Professor of Ceramic Engineering and Co-Director of the Institute for Security Science and Technology at Imperial College. His research covers processing-property-microstructure relations in refractories, whitewares, nuclear and ultra-high temperature ceramics. Bill was made a Fellow of the Royal Academy of Engineering in 2012, was President of the American Ceramic Society from Oct 2016 to Oct 2017 and became a Foreign Fellow of the Indian National Academy of Engineering in 2017.

Dr Finn Giuliani

Dr Finn Giuliani joined us in April 2009 as a joint lecturer between the Departments of Materials and Mechanical Engineering. Finn came to Imperial from Linköping University, Sweden, where he was an Assistant Professor.

Finn has a PhD from the University of Cambridge where he examined small scale plasticity in multi-layered ceramics coatings. Particular emphasis was placed on measuring and observing small scale plasticity at elevated temperatures. His BEng in Materials Science and Engineering is from the University of Bath. While in Sweden he concentrated on deformation of a group of nanolaminated ceramics known as MAX phases. These are a group of ternary nitrides and carbides, for examples Ti_3SiC_2, which combine ceramic and metallic properties. However, of particular interest is their ability to dissipate energy through reverse plasticity. This continues to be a topic of research.

The focus of the majority of his research at this time is small scale mechanics particularly stable small scale fracture experiments. These allow the properties of interfaces and grain boundaries to be measured directly.

Dr Luc Vandeperre

Dr Luc Vandeperre, currently a reader in the Department of Materials, joined the CASC academic staff in July 2010. He is currently the Deputy Director of CASC and ICO-CDT Director of the Centre for Doctoral Training in Nuclear Energy.

Luc joined Imperial College in 2006 from the University of Cambridge, where he was a post-doctoral research associate. During his PhD at the Catholic University of Leuven (Belgium), he investigated the electrophoretic deposition of layered ceramic shapes, and was awarded the 1997 Scientific Prize of the Belgian Ceramic Society for his work. Since then, he has worked in both commercial, as well as, academic environments researching the shaping of ceramics and understanding their thermo-mechanical properties. In addition to his PhD research he has carried out research on shaping ceramics and ceramic foams using natural binders such as starch and gelatine, thermal shock of ceramics, fracture of laminated ceramics, fracture of porous brittle materials, and the relation between hardness and deformation mechanisms. He also designed a device capable of thermal compensation of fibre Bragg gratings for optical data transmission.

Dr Vandeperre's current research spans two themes. The first is thermo-mechanical properties of structural ceramics, where he is investigating ceramics for use in high temperature environments and as ballistic protection. A second theme is environmental technologies. In this area, he is involved in research into cements for nuclear waste encapsulation, tailoring materials for anion removal from water and producing high value products from industrial by-products.

Dr Alba Matas Adams

Alba joined the Department of Materials as Technical Manager in November 2016. Prior to this, she was a PhD student at ICIQ (Tarragona), researching on new materials for bio- and energy related applications. She is involved in technical and administrative activities for the Centre for Advanced Structural ceramics (CASC) and two projects (XMAT and RESLAG). She has experience working on the development of wide range of materials. She also engages herself in other programmes within the Department of Materials.

Garry Stakalls

Garry Stakalls started as technician for the Centre in July 2008. Prior to this he worked in the Materials Processing Group within the Department of Materials, where he commissioned and ran large experimental rigs and was involved in the processing of wide range of materials. His main activities have been to use, and train new users, on the use of the thermal analysis equipment as well as operating the hot press for sintering and pressing. He also maintains the equipment while liaising with Netzsch for thermal analysis and FCT for the hot press.

Imperial College Research Fellows

Dr Nasrin Al Nasiri	Imperial College Research Fellow
Dr Samuel Humphry-Baker	Imperial College Research Fellow

Researchers

Dr Eleonora D'Elia	Research Associate
Dr Daniel Glymond	Research Associate
Dr Sum Wei Siang	Research Associate
Dr Eugenio Zapata-Solvas	Research Associate
Dr Claudio Ferraro	Research Associate
Dr Iuliia Elizarova	Research Associate

PhD students

Cyril Besnard	**Jindaporn Juthapakdeeprasert**
Eleonora Cali	**Alan Leong**
Ben Currie	**Wirat Lerdprom**
Justine Delage	**Annalisa Neri**
Ezra Feilden-Irving	**Kristijonas Plausinaitis**
Claudia Gasparrini	**Dimitri Pletser**
Tommaso Giovannini	**Giorgio Sernicola**
Yun-Hao Hsieh	**Jia Hui Teo**
Charles Hutchison	**Qiaosong Cai**
Stuart Aberdeen	

Visitors

Dr Elena Xuriguera Martin	Universitat de Barcelona, Spain
Dr Adelina Braun	Merck, Germany
Dr Wakako Araki	Saitama University, Japan
Dr Arash Moaveni	Welland Medical, UK
Mr Amin M'Barki	Saint Gobain, France
Mr Andrew Corker	Liverpool University, UK

CASC Alumni 2016-2017

Gil Machado	Research Engineer at Zimmer Biomet, Swindon, UK.
Esther Garcia Tuñon Blanca	Lecturer in Materials Science and Engineering, SSLC Chair for MECH Eng, Liverpool, UK
Ayan Bhowmik	Research Fellow at Rolls-Royce@ NTU Corporate Lab, Singapore.
Laura Larrimbe	R&D Engineer-Materials Scientisc, Sandvik Hyperion, Barcelona, Spain.
Claudio Ferraro	Materials Researcher in Front and Innovation at Beiersdorf, Hamburg, Germany.
Michael Rushton	Senior Lecturer, Bangor University, Wales, UK.
Ezra Feilden Irving	Graduate Engineer at Meggitt Sensing Systems, Basingstoke, UK.
Na Ni	Associate Professor in the School of Mechanical Engineering at Shanghai Jiao Tong University, China.
Cyril Besnard	

RESEARCH

Research Fellow Projects

- **Name: Dr Nasrin Al Nasiri**
  Project title: Environmental barrier coatings for jet engines application.
  Mentor: Prof Eduardo Saiz.
  Sponsor: Rolls-Royce and Imperial College London.

The need to increase the cycle efficiency and reduce noise and NOx emissions from engines has promoted the development of ceramic matrix composites (CMC) such as silicon carbide (SiC-SiC). The use of CMCs will lead to a significant improvement in fuel consumption and weight savings of up to 30% compared to Ni-based super alloys.

Si-based ceramics have excellent oxidation resistance due to formation of a protective silica layer on reacting with dry air. However, the same silica layer will react with water vapour to form gaseous silicon hydroxide, leading to high recession and component failure. To avoid this behaviour, a prophylactic environmental barrier coating (EBC) is required. A variety of EBCs have been developed in the past consisting of a minimum of 4 layers requiring a costly application method such as plasma spraying. The main aim of the work is to develop a reliable single layer of EBC, develop a low cost applying method and studying the corrosion behaviour.

We have selected four rare earth monosilicates as promising EBCs based on their thermal performance: Erbium (Er), Yttrium (Y), Ytterbium (Yb) and Lutetium (Lu). We have developed a patented wet processing technique to apply water-based RE-oxides on CMC samples previously oxidised in dry air to produce protective SiO2 layer. The samples are subsequently fired to promote reactive sintering and adhesion. The advantages of this non-line of sight method are: 1) it provides better adhesion, 2) it is a low cost and easy to use method, 3) it can be applied to any complex shape and size and 4) it has 100% powder efficiency leading to dramatic cost savings in coating materials. This new coating technology will lead at least to the following advantages: 1- Operational savings (10-15% higher fuel efficiency), 2- Production savings (up to $100K per engine) and 3-Reduction of emissions by 25-30%. This will result in more efficient, lighter, faster, cheaper, less noisy and less polluting gas turbines.

- **Name: Dr Samuel Humphry-Baker**
  Project title: Metal-ceramic composites in fusion reactor environments.
  Mentor: Dr Luc Vandeperre.
  Sponsor: Imperial College Research Fellowship

Powder-processed composites based on the carbides and borides of tungsten are used extensively in manufacturing tools and mining applications, however they have been recently identified as promising materials for nuclear fusion reactors[1]. In both applications, these materials are exposed to very high temperatures, mechanical stresses and oxidation, while in fusion devices irradiation damage poses an additional challenge.

This project is focussed on tailoring these materials to enhance their performance in extreme environments. Our strategy is based on developing enhanced metal-ceramic composites, whereby ceramic particles are combined with a small amount of ductile metallic alloy to improve the overall mechanical properties and manufacturability. The defining microstructural feature of these composites is their high density of metal-ceramic interfaces. These interfaces control heat transport, vacancy diffusion, and dislocation motion – and are therefore key to understanding their interesting properties. By engineering the density and chemistry of these interfaces using advanced processing techniques, we will design materials that can be employed in more demanding conditions.

The work can be divided into several complimentary work streams. First, materials will be processed at Imperial, using advanced powder consolidation equipment such as the vacuum hot-press. Sintering studies will be aided by the state-of-the-art thermal analysis facilities within CASC. Once synthesised, materials will be studied under oxidation[2] and mechanical stresses at Imperial – predominantly using the thermogravimeter and temperature creep tester. Complimenting this work, irradiation studies will be conducted at external facilities and brought back to college for post-mortem characterisation. The work benefits from on-going collaboration with Tokamak Energy Ltd and their supporting of a PhD studentship within the Nuclear-CDT.

References:
1. *Modelling the power deposition into a spherical tokamak fusion power plant*. C.G. Windsor, J.G. Morgan, P.F. Buxton, A.E. Costley, G.D.W. Smith, A. Sykes Nucl. Fusion. 57 , 36001, 2016.
2. *Oxidation resistant tungsten carbide hardmetals*. S.A. Humphry-Baker, K. Peng, W.E. Lee, Int. J. Refract. Met. Hard Mater. 66, p: 135–143, 2017.

PDRA Projects

- **Name: Dr Eleonora D´Elia**
  Project title: Living Materials.
  Supervisor: Prof Eduardo Saiz.
  Sponsor: DARPA.

Smart materials have captivated the world of science and technologies for decades. The idea that a man-made material could sense the environment and respond to external stimuli such as light, temperature, or damage in an autonomous and programmed way is fascinating and, at the same time, closer than anticipated.

In this work we describe an approach for the fabrication of adaptive composite materials able to self-repair autonomously, sense mechanical stimuli such as pressure or flexion self-monitor their structural integrity and change their shape in response to external stimuli. These smart materials are based on the controlled integration of microscopic electrically conductive networks within polymeric matrices having self-healing or shape-memory capabilities. To realize this concept, we have taken advantage of the 2D nature of graphene combined with new processing techniques to design minimally-invasive networks able to provide a platform for inducing electrical stimuli in the composites. Superlight electrically conductive carbon-based networks with microscopic porosity obtained by freeze-casting have been infiltrated with a second polymeric phase. The networks are tailored to provide controlled and localized joule heating at relatively low voltages in order to stimulate the desired response in the polymeric matrix (healing or shaping). The resulting materials have graphene contents below 0.5 wt. %. Their mechanical response (strength and toughness) is evaluated and related to their microstructure.

Their healing ability is quantified in terms of recovery of these mechanical properties after damage. In parallel, their shape changing and mechanical sensing capabilities in response to electrical currents are also tested. Preliminary results on shape-memory compositions show strengths up to 60 MPa and complete shape recovery through joule heating in 10 seconds. Furthermore, the composites are able to record, through a conductivity change, the initiation and progression of a crack, providing damage monitoring capabilities.

The work brings together the fields of construction, materials science, robotics, energy and bioengineering in an innovative way, opening new paths for the design of smart actuators and adaptive composites.

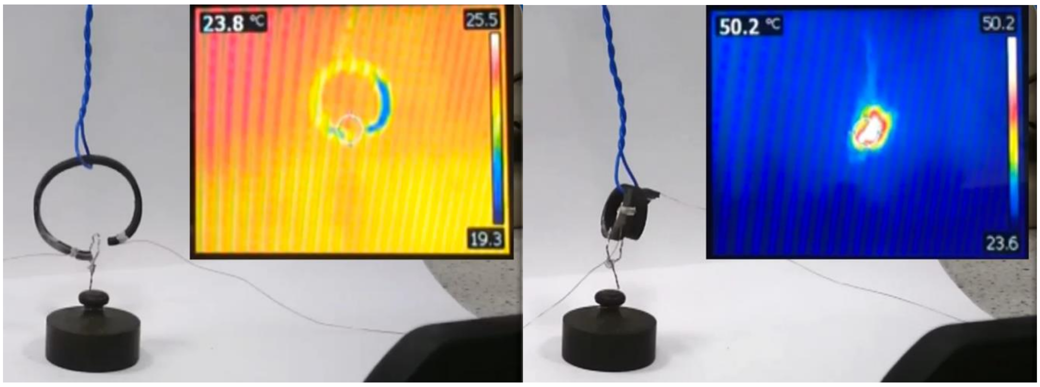


Figure1. *Joule heating effect in a shape-memory conductive sample showing the sample curling up and grabbing a weight due to current being passed through it.*

- **Name: Dr Eleonora D'Elia**
  Project title: RESLAG.
  Supervisor: Prof Eduardo Saiz.
  Sponsor: HORIZON 2020.

The European steel industry generated about 21.4 million tons of slag in 2012 resulting from steel making. About 24% is not being reused, representing a severe environmental problem in Europe, but also a huge amount of available material for potential recycling. RESLAG will face this environmental problem by providing 4 eco-innovative industrial alternative applications to valorise the steel slag.

The main objective of RESLAG project is to valorise the steel slag that is currently not being recycled (right now it is partially landfilled and partially stored in the steel factories) and reuse it as a raw material for 4 innovative applications that contribute to a circular economy in the steel sector with an additional cross-sectorial approach. These applications will be demonstrated at pilot level and led by end-user industries. Altogether open enormously the range of possibilities of taking profit from slag not only for the steel sector but also for many other sectors.

RESLAG is coordinated by CIC Energigune (Spain) and has 19 academic and 4 industrial partners, Imperial College is a fundamental partner involved in the mechanical, thermal and optical characterization of the slag pebbles as receive and the produced refractories used in the steel industry.

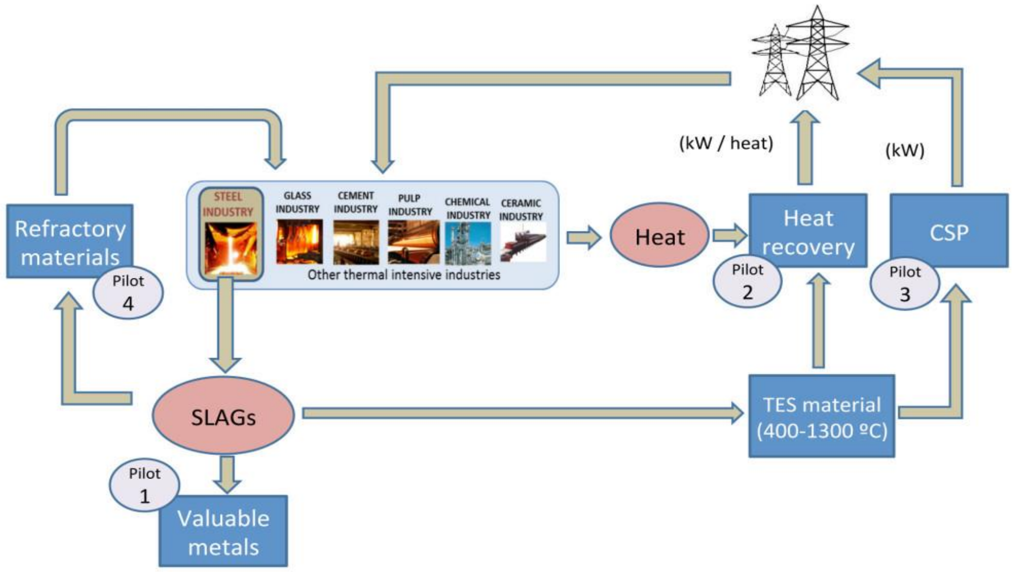


***Figure 2** – RESLAG Project Main Concept design.*

- **Name: Iuliia Elizarova**
  Project title: Manufacture using Advanced Powder Processes (MAPP).
  Supervisor: Prof Eduardo Saiz, Dr Luc Vandeperre and Dr Finn Giuliani.
  Sponsor: EPSRC

MAPP is the EPSRC Future Manufacturing Hub in Manufacture using Advanced Powder Processes. MAPP's vision is to deliver on the promise of powder-based manufacturing to provide low energy, low cost, and low waste high value manufacturing routes and products to secure UK manufacturing productivity and growth. MAPP is led by the University of Sheffield and brings together leading research teams from the Universities of Leeds, Manchester and Oxford, and Imperial College London, together with a founding group of 17 industry partners and the UK's High Value Manufacturing Catapult.

Imperial's work centres around the manipulation of the microstructure of ceramic-based materials fabricated using wet processing technologies (e.g. 3D printing by continuous extrusion or freeze casting). The goal is to understand and control the distribution of particles and fibres in order to create complex textures. This will involve the development of real time experiments and measurements as well as models and systematic structural and mechanical characterization. Possible applications are printing of ceramic composites with structural and/or functional capabilities (fibre of platelet-reinforced composites, thermoelectrics….).

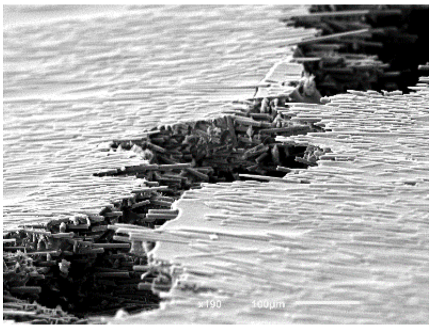


Figure 3. *Fracture of a 3D printed fibre reinforced composite*

- **Name: Claudio Ferraro**
  Project title: Fabrication of Graphene Coatings on Advanced High Strength Steel.
  Supervisor: Prof Eduardo Saiz.
  Sponsor: AcerlorMittal.

The key objective of this project, sponsored by Arcelor Mittal, is the production of graphene coatings on steel substrates through Electrophoretic Deposition (EPD). These coatings will serve as a protection from oxidation for the high alloyed steel substrate. The production process of this steel, indeed, includes an annealing step, used to recover some mechanical ductility, which partially oxidase the steel substrate. Graphene is known in literature to be an excellent barrier to oxygen diffusion that is why has been selected for this aim. EPD is a simple and quick deposition technique, resulting compatible with the rate of the steel production process. The graphene coatings will be characterised in terms of adhesion to the steel substrate, and protection from oxidation and zinc wettability, as galvanisation with this metal is a further step of the steel processing.

- **Name: Dr Daniel Glymond**
  Project title: Transpiration Cooling Systems for Jet Engine Turbines and Hypersonic Flight.
  Supervisors: Dr Luc Vandeperre and Prof Bill Lee.
  Sponsor: EPSRC.

Thermal protection systems for hypersonic flights are expected to have to operate with component temperatures in excess of 2000 ºC, leaving only a small group of materials with sufficient high melting points. Ultra-High Temperature Ceramics (UHTC) have become the lead candidates for the development of such protection systems also due to their high thermal conductivity which enables heat to be conducted laterally thus reducing the maximum temperatures of the sharp leading edge. The basis of transpiration cooling is the introduction of a cool layer of gas between the component and the hot freestream flow, reducing the heat flux to the material (Figure 4).

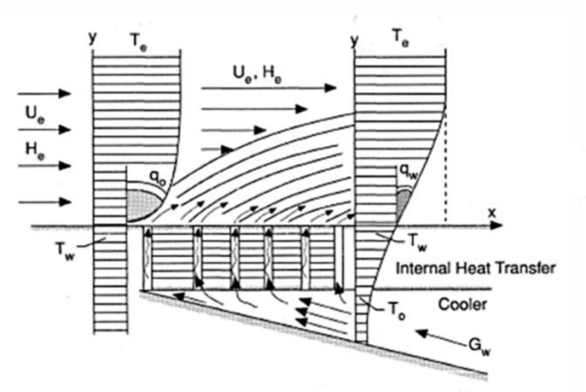


Figure 4. *Transpiration cooling system*

UHCTs with controlled porosity are suitable for application in transpiration cooling systems. This work addresses the manufacturing of innovative porous UHTCs by establishing a densification route which does not require pressure and allows producing the components in the correct shape without requiring extensive machining or large amounts of material loss. Samples of ZrB_2 with homogenous porous structures were manufactured by partial sintering or by addition of different volume fractions of fugitive inclusions, using starch as a pore former (Figure 5).

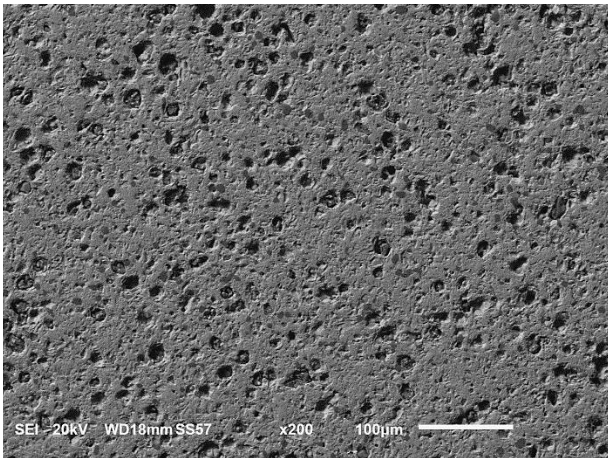


Figure 5*. Pressureless sintered ZrB_2 using starch as a fugitive agent*

Characterization of the sintered porous UHTCs was focussed on measuring systematically the relationship between pore structure, porosity and some properties such as thermal conductivity, strength or flow. All this information enables to select the most relevant candidate which is able to maintain excellent thermal and structural properties with increased porosity

Future research will focus on the generation of designed porous structures.

- **Name: Dr Eugenio Zapata-Solvas**
  Project title: Carbides for Future Fission Environments.
  Supervisor: Prof Bill Lee.
  Sponsor: EPSRC.

The aim of this project is to develop new Zr-based carbides, including Zr-based MAX phases, for coating Zr-alloys cladding in fission reactors of future nuclear power plants. The synthesis, sintering by hot press and spark plasma sintering and microstructural characterization by XRD, SEM and TEM of the different Zr-based carbides is done at Imperial College. The research has been focused on the effect of processing and of the impurities in the synthesis of sub-stoichiometric ZrC_{1-x}, and $Zr_{n+1}AlC_n$ and $Zr_{n+1}SiC_n$ MAX phases, being able to synthesize Zr_3AlC_2 with the highest yield reported till date.

Currently, quinary MAX phases are being manufactured and a study about how the addition of more elements increases MAX phases stability and potentially their yield is under investigation.

PhD Projects

- **Name: Cyril Besnard**
  Project title: Si Doping of Boron Carbide.
  Supervisor: Dr Luc Vandeperre and Dr Finn Giuliani.
  Sponsor: DSTL.

  The aim of this project, supported by the Defence Science and Technology Laboratory of the UK, is to develop novel ceramics for use in armour. Lightweight impact resistance ceramics are still under development. B_4C is attractive and has already been used for this application for many decades. However catastrophic failure occurs in B_4C at the high pressures achieved during high velocity impacts, which is due to collapse of a weak polytype within the structure. Previous research has suggested that doping with silicon can eliminate this polytype and therefore improve the high velocity impact performance of B_4C. Therefore the aim of this project is to produce meaningful quantities of Si doped B_4C which can be used for high speed impact testing. This project is also in collaboration with the shock physics group at Imperial College.

- **Name: Qiaosong Cai**
  Project title: Robocasting of complex structural ceramics.
  Supervisor: Prof Eduardo Saiz, Dr Luc Vandeperre and Dr Finn Giuliani.
  Sponsor: CASC Industrial Consortium.

  Robocasting is a distinct additive manufacturing technique that can be used to print complex structural ceramics. In robocasting, inks are extruded out through a nozzle to build 3D objects layer by layer. By using colloidal inks, hydrogel inks, emulsion-based inks or foam gel inks, dense or porous ceramics can be printed by robocasting.

This project focusses in the development of novel ink formulations to print complex composite structures. In particular, co-extrusion will be used to print lines with hollow cores or materials reinforced by continuous fibres (e.g. metal fibres in ceramic matrix).

The inks are prepared by using Pluronic® solutions as the particle carrier. This kind of hydrogel ink is sensitive to the temperature and has a suitable rheology for robocasting. Microporous structures are printed using emulsion-based inks that allow the simultaneous control of macroscopic shape and microscopic porosity.

- **Name: Eleonora Cali**

  Project title: Magnetic Nanoparticles for Uranium Sensing and Removal from Solution.
  Supervisors: Dr Luc Vandeperre and Prof Mary Ryan.
  Sponsor: EPSRC, DISTINCTIVE Consortium.

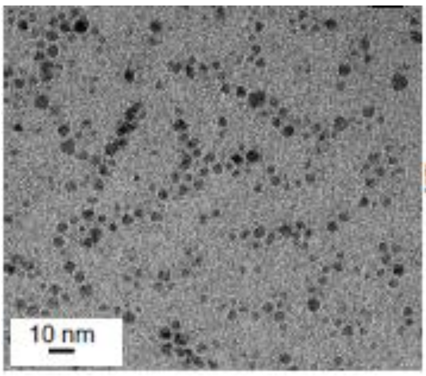


Figure 6. *TEM micrograph of the magnetite nanoparticles*

Magnetic nanoparticles functionalised with surface groups for sorption of specific species are advantageous over other sorption methods because a magnetic field can easily separate them from solution and guide them to assay specific locations. Therefore this project aimed to produce magnetic nanoparticles functionalised to remove uranium ions from solution as well as to create a vehicle for assaying the presence of uranium in small quantities in installations to be decommissioned.

Magnetite (Fe_3O_4) nanoparticles were successfully produced, see Figure 8, and after functionalization with phosphate groups showed a high sorption capacity for U(VI): 1690 mg U per gram nanoparticles.

Kinetic experiments showed that the sorption is also very fast and the lack of Ca, Mg and Sr sorption demonstrates that the particles are highly selective for U, see Figure 7.

Further tests reproduced solution chemistries as found in selected SIXEP effluents at the Sellafield site and the high selectivity for U remained valid with no other ions removed. Moreover, effective sorption was maintained even when the U

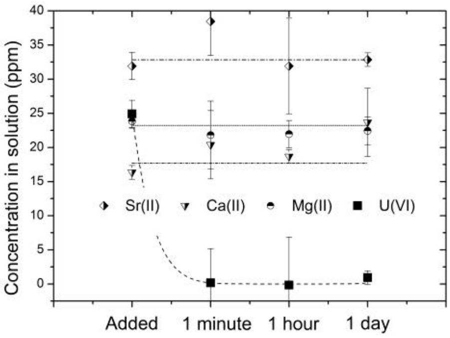


Figure 7. *Competitive sorption tests*

- **Name: Ezra Feilden-Irving**

  Project title: Additive Manufacturing of Ceramics and Composites.
  Supervisors: Dr Finn Giuliani, Prof Eduardo Saiz and Dr Luc Vandeperre.
  Sponsor: CASC Industrial Consortium.

Additive manufacturing is reasonably well established for the production of conventional ceramic parts with complex geometries, but little attention has been given to more exotic ceramics and ceramic composites. It is highly desirable to print a number of these materials, as many of their applications require short production runs of small batches of parts. In the present work we use a 3D printing technique known as robocasting, which consists of continuous extrusion of pastes, to print a range of ceramic materials, ceramic matrix composites, and polymer matrix composite parts. The shear forces in the nozzle during printing can be tuned to give highly textured microstructures when the paste consists of anisotropic particles (such as short fibres, platelets), which heavily effect the strength, toughness and other mechanical properties of the materials. These have been measured using a new in-situ SEM DCB method, and compared to conventionally produced material.

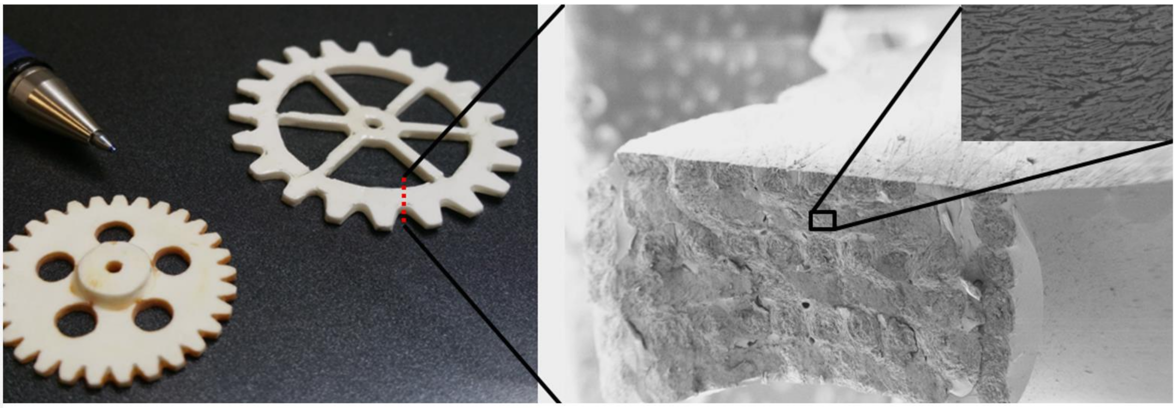


Figure 8. *A pair of ceramic composite parts produced by robocasting, consisting of a network of highly aligned Al_2O_3 platelets infiltrated with epoxy.*

- **Name: Claudia Gasparrini**
  Project title: Oxidation of Carbides for Fast Breeder Fuel.
  Supervisors: Prof Bill Lee and Dr Luc Vandeperre.
  Sponsor: EPSRC DISTINCTIVE Consortium/NDA/NNL.

Oxidation of ZrC and UC was investigated via experiments on ZrC hot pressed specimens and on depleted UC pellets and fragments in a furnace and with an in situ technique: High Temperature Environmental Scanning Electron Microscopy (HT-ESEM).

The Maltese cross shape of the oxide formed during ZrC oxidation was investigated with HT-ESEM experiments at 1073 K in 200 Pa O_2 atmosphere. Its formation mechanism is found to be comprised of three steps: edges delamination, crack formation at corners and crack propagation towards the inner core with formation of microcracks parallel to the interface. Microcracks are formed due to debonding of the interface which occurs when the oxide reaches approximately 20 µm thick. High Resolution TEM revealed the oxide/carbide interface to be comprised of a 2 µm thick amorphous carbon matrix with nanocrystals of ZrO_2 embedded in it.

The influence of temperature on the oxidation mechanism of UC was investigated with fragments oxidised in air in a furnace and in a HT-ESEM in an oxygen atmosphere from 673 – 1173 K. Oxide morphology, conversion and specific surface area (SSA) were significantly affected by temperature, e.g. oxidation at 873 K gave a product with greater SSA and conversion compared to higher temperature of oxidation. Samples oxidised at 873 K in the HT-ESEM showed instantaneous oxidation on the entire sample surface after insertion of oxygen, while samples oxidised at T > 873 K showed partial sintering of the oxide which acts as a diffusion barrier and limits the occurrence of oxidation of UO_2 to U_3O_8 to cracked surfaces.

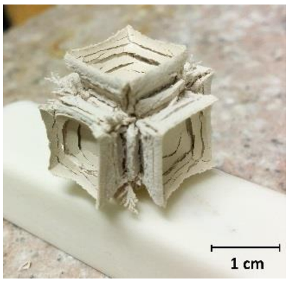


Figure 9. *Details of the Maltese cross shape of the oxide formed when a 1cm cube specimen of ZrC is oxidised in air at 1000°C for 4h.*

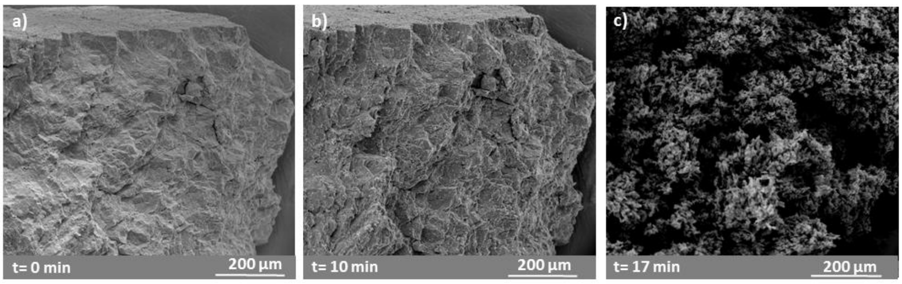


Figure 10. *a) SEI showing in situ oxidation of a UC fragment at 600 °C in 50 Pa O_2 atmosphere at t=0 min:, b) SEI showing in situ oxidation of a UC fragment at 600 °C in 50 Pa O_2 atmosphere at t=10 min: c) details of the typical popcorn like transformation due to oxidation from UO_2 to U_3O_8*

❖ **Name: Tommaso Giovannini**

Project title: Plastic behaviour of ceramics coatings – an experimental & computational characterization.

Supervisors: Dr Finn Giuliani and Dr Daniel Balint.

Sponsor: SECO Tools.

With the global cutting tool market predicted to reach $54.6 billion by the year 2021, there is a strong need for improved cutting tools which are able to withstand the stringent time and cost requirements of modern manufacturing. Thin ceramic coatings (≤ 10 µm), deposited onto cemented carbide inserts using chemical vapour deposition (**CVD**), have been used since the end of the 60s to improve cutting tool performance and lifetime. Although the quality of the deposited coatings has improved considerably a deeper understanding of the microstructural mechanisms which govern wear in the coatings is required to allow for further improvement of coating performance. This understanding is closely linked to the localized plastic deformation behaviour which has been observed in coatings after metal cutting operations (**Figure 11a**).

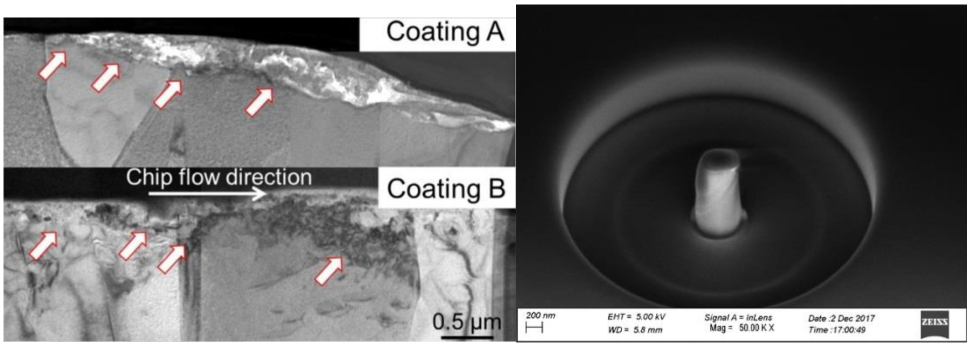
❖ 

***Figure 11a**)-Bright field TEM images in α-Al_2O_3 coatings highlight the presence of dislocation activity close to the surface (0.5 - 1 µm deep)[1]. **b)** Micropillar compression performed on the α-Al_2O_3 coatings highlights plastic slip activity in the coating materials at reduced length scales.*

High temperature nanoindentation and micropillar compression experiments (**Figure 11b**) can be used to provide an initial characterization of the coating's plastic response at increasing temperatures. Crucially, these experiments can also be used to extract inputs for a discrete dislocation modelling (**DD**) framework aimed at better understanding the plastic behaviour of the coatings. By investigating the relationships existing between plastic activity, the presence of defects, such as grain boundaries and thermal cracks, and overall cutting tool performance, the hope is to highlight which microstructural features are associated with localized coating failures. These are closely linked to tool lifetime and their elimination presents a strong opportunity for improving overall cutting tool performance.

Reference:

1. *Microstructure and wear mechanisms of texture-controlled CVD α-Al2O3 coatings*. R. M'Saoubi, O. Alm, J.M. Andersson, H. Engstrom, T. Larsson, M. P. Johansson-Joesaar, M. Schwind.Wear,376-377, p:1766-1778, 2017.

- **Name: Yun-Hao Hsieh**

Project title: Ceramic Wasteforms for Advanced Fuel Cycle Reprocessing.
Supervisors: Prof Bill Lee and Prof T.D. Waite (UNSW, Sydney, Australia).
Sponsor: The UNSW Tyree Scholarship.

Many advanced reprocessing technologies have been designed and developed to meet the future nuclear waste policies and further separate waste. One of the most promising advanced reprocessing methods, EURO-GANEX (Group Actinides Extraction), is nowadays being developed and aim to further separate both major (U, Pu) and minor (Np, Am, and Cm) actinides together from fission products. In that context, new advanced immobilization matrices capable of accommodating such modified waste streams have to be investigated[1, 2].

Synroc and borosilicate glass are potential wasteforms that have proven themselves to be efficient to immobilize high-level nuclear wastes (HLW) [3]. In this project, a new composition of Synroc, "Synroc-Z", is designed and characterized. The primary modification is to reduce the amount of zirconolite phase, which acts as the main host for actinides.

Synroc-Z has been prepared via hot uniaxial pressing (HUP), with optimized process conditions to obtain dense samples. A well-known borosilicate glass, R7T7, was melt to compare with HUPed Synroc-Z. In both wasteforms, their durability via the MCC-1 test at 90^{o}C and microstructure after corrosion was tested.

The mass loss before and after leaching test for Synroc-Z was negligible (< 0.02%), while for the R7T7 glass it was relatively larger (>0.35%). Nano TiO_2 particles (~50 nm) were formed on the perovskite-rich surface. The thickness of TiO_2 skin was determined via AFM which was ~60 nm. In the leached sample, which were polished to 1 μm, it can be clearly observed that TiO_2 particles were assembled on the brighter contrast area while the TiO_2 particles were dispersed on the rougher (15 um polishing) Synroc-Z surface but dense on the edge of holes. The leached R7T7 glass formed Al, Zn and Si rich layer on the surface. The ratio of Al, Zn and Si of layer on the surface is ~1: 2: 4 while the composition of unleached R7T7 glass is ~2: 1: 18.

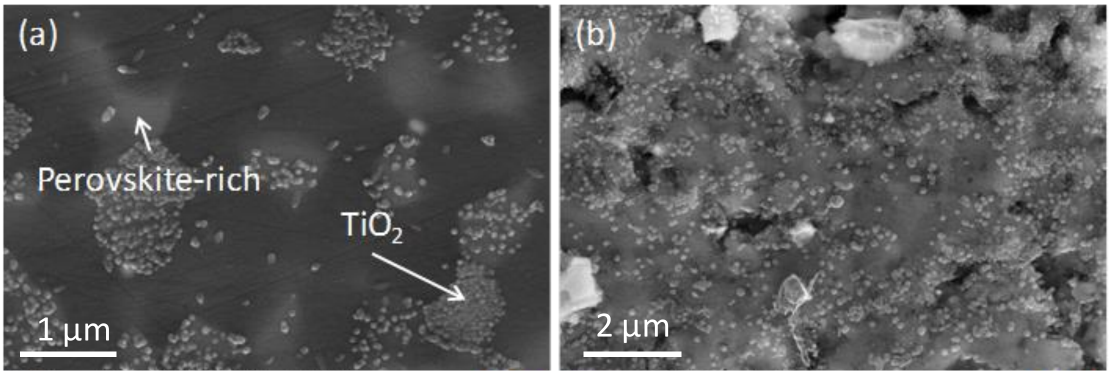


Figure 12. *SEM images of 20 wt.% waste loading HUPed Synroc-Z samples with (a) 1 μm and (b) 15 mm polishing finish. The TiO_2 particles compact on perovskite-rich regions. Samples with 15 μm polished shows dispersed TiO_2 skin but dense in some edges of holes.*

References:

1. *Advanced Separation Techniques for Nuclear Fuel Reprocessing and Radioactive Waste Treatment* K. L. Nash and G. J. Lumetta, . Elsevier Science, (2011).

2. *Development of a New Flowsheet for Co-Separating the Transuranic Actinides: The "EURO-GANEX" Process*. M. Carrott, K. Bell, J. Brown, A. Geist, C. Gregson, X. Hères, C. Maher, R. Malmbeck, C. Mason, G. Modolo, U. Müllich, M. Sarsfield, A. Wilden, R. Taylor. Solvent Extraction and Ion Exchange, 32[5], p: 447-67, 2014.

3. *Radioactive waste forms for the future*. W. Lutze and R. C. Ewing. North-Holland, 1988.

- **Name: Charles Hutchison**
  Project title: Glass Composite Materials for Radioactive Waste Immobilisation.
  Supervisor: Prof Bill Lee.
  Sponsor: EPSRC and Sellafield.

  This project examines Glass Composite Materials (GCMs), which may contain several crystal phases, as wasteforms for some of the Difficult Intermediate level Wastes from the Legacy Ponds and Furloes at Sellafield. The GCMs have been made by Plasma Vitrification and Joule Heated In-Container Vitrification (JHICV). Standard characterisation techniques such as XRD, SEM and EDX are being used to determine the phases in GCMs before and after leach studies, in varying conditions. This will allow tracking of how crystalline components affect the durability and ultimately whether these GCMs can be safely disposed of.

- **Name: Jindaporn Juthapakdeeprasert**
  Project title: Development of Multifunctional Cement Kiln Refractory Coatings.
  Supervisor: Prof Bill Lee.
  Sponsor: SCG Cement-Building Materials.

  To produce OPC Clinker, cement industry has to consume a high amount of fuel; lignite, coal… each year. Approximately 10-15% of the energy is lost to the atmosphere through refractories and external surface. Developing a coating with low thermal conductivity could prevent the heat loss from the cement kiln. However, if the coating is to be used at a riser duct, cyclone, kiln lining and cooler of the cement kiln, other functions must also be taken into consideration. The coating must also have high mechanical, thermal and chemical stress resistance to be able to withstand high temperatures (>1500^{o}C), clinker dust abrasion and chemical corrosion of alkaline, sulphur or chloride gases. Therefore, this multifunction coating would not only reduce energy usage but also protect the refractories surface and decrease restoration coat and time which lead to an extraordinary cost saving.

- **Name: Alan Leong**
  Project title: Graphene Coatings for Pipelines.
  Supervisors: Prof Eduardo Saiz and Dr Cecilia Mattevi.
  Sponsor: Petronas, Malaysia.

  Graphene is a 2D material with unique functional and mechanical properties, from tuneable electrical and optical response to high intrinsic stiffness and strength, chemical versatility, controllable permeability or extremely high specific surface area. It has the potential to revolutionize a wide range of technologies from batteries to composites and membranes. However, to achieve this goal we need to develop ways to integrate graphene into fabrication technologies and to develop approaches to synthesize large quantities of material tailored for specific applications.

Graphene is a very appealing reinforcing phase for polymer pipeline liners/coatings. The addition of graphene can provide controlled permeability, enhanced mechanical properties and even sensing capabilities. However, neither mechanical exfoliation nor chemical vapour deposition are amenable to the large-scale synthesis of graphene needed for this application. We will address this need by using chemically modified graphene (CMG) that can be fabricated in bulk quantities. CMG intrinsic surface area, permeability and mechanical properties are comparable to pristine graphene and combined with its unique chemical versatility it opens exciting possibilities for the development of novel composites.

- **Name: Wirat Lerdprom**
  Project title: Impact of Fast Firing on Phase Evolution in White-ware Ceramics.
  Supervisor: Prof Bill Lee.
  Sponsor: Cementhai Ceramics Co., Ltd, Thailand

Porcelains are clay based materials, used extensively in household, scientific and engineering applications, which are produced via viscous flow sintering. The sintering process of porcelains is not only to densify the green body, but also to induce mineralogical phase changes. Densification and phase evolution are influenced by sintering conditions i.e. heating rate, dwell time, atmosphere, and temperature.

New advanced sintering processes have been introduced aiming to improve product quality and energy usage efficiency such as conventional fast firing (CS), spark plasma sintering (SPS), flash sintering (FS) and microwave sintering (MWS), each of which has different process parameters.

The aim of this work is to investigate microstructural and physico-mechanical property changes (apparent bulk density, water absorption, Vickers hardness, and fracture toughness) in a porcelain body sintered using the 4 techniques and consider energy, financial and other aspects to determine which is most likely to find industrial application. The study involves investigation of mullitization, glass formation, and quartz dissolution from the different sintering techniques using X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and energy-dispersive spectroscopy (EDS). Finally, the ultimate goal of this work is to develop understanding of process parameters i.e. heating rate, pressure, atmosphere, electric field, and microwave radiation on mineralogical composition and densification in porcelains.

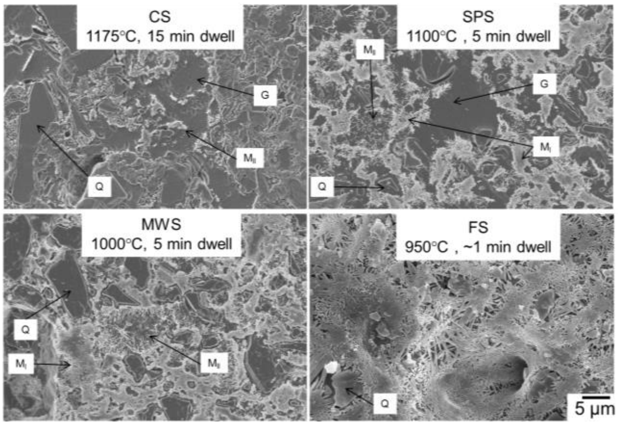


Figure 13. *SEM-SE images of conventional sintered (CS), spark plasma sintering (SPS), microwave sintering (MWS), and flash sintered (FS) porcelain samples; showing etched samples using 20% HF (Ml=primary mullite, Mll=secondary mullite, G=glass, and Q =Quartz).*

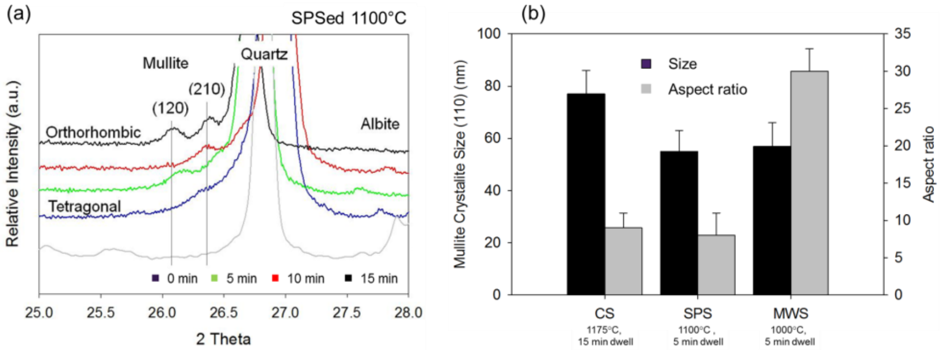


Figure 14. *(a) XRD patterns of the SPSed samples showing different mullite crystal structure as a function of dwell times, (b) mullite crystallite size and aspect ratio of the porcelains sintered using different techniques.*

- **Name: Annalisa Neri**

  Project title: Development of a Novel Wound Management Dressings.
  Supervisor: Prof. Eduardo Saiz.
  Sponsor: Welland Medical Ltd.

Wound management represents a challenging field, not only in research and product development but also in clinic, where patients present an array of wound types. In particular, infection is a common problem in wound healing: this can result in reduced healing rates, prolonged hospitalization time and increased care costs.

The focus of this study is to develop and characterise a novel dressing comprising collagen and honey which is able to actively promote healing while preventing infection in a variety of wound types.

Collagen presents several properties that are desirable for a wound dressing: strong biocompatibility, weak antigenicity, biodegradability and in addition it can terminate the chronic state of a wound. The honey component exhibits anti-inflammatory and anti-bacterial properties, while also allowing for manipulation of the wound pH. Herein the combination of collagen and honey is investigated for the design of a novel bioactive wound dressing film able to actively promote healing.

This material is intended to adhere and conform to the wound site and to degrade in contact with wound exudate. The collagen-honey films produced (Fig. 15) are being characterised in terms of chemical homogeneity, degradation rate, mechanical properties, antibacterial activity and cells response.

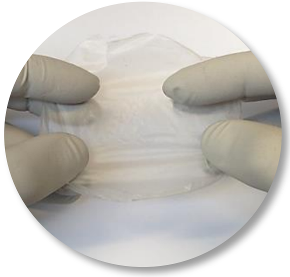


Figure 15. *Collagen-honey based films*

- **Name: Kristijonas Plausinaitis**
  Project title: Adsorption of Heavy Metals and Radionuclides on Cement Phases.
  Supervisors: Dr Luc Vandeperre and Prof Mary Ryan.
  Sponsor: Amec Foster Wheeler.

Lead (Pb) is one of the constituents in intermediate level radioactive waste. Due to its high toxicity, it is of particular importance to understand the behaviour of soluble Pb ions, in particular their sorption on and migration within the cement backfill, one of the main proposed engineering barriers for geological waste disposal.

Of particular interest for understanding the long term safety of these engineered barriers is how the evolving cement matrix may affect efficacy of capture of mobile species by sorption and /or precipitation processes.

In this work, batch sorption analysis of Pb on to hydrated Nirex Vault Reference Backfill (NVRB) cement powder indicates a Langmuir like process: a linear uptake followed by a plateau due to saturation at increasing concentrations. Leaching experiments were also carried out and suggested that the sorption process is reversible.

The homogeneity of surface interaction was analysed using spatially resolved chemical analysis. In particular we have used scanning electron microscopy (SEM), energy dispersive X – ray spectroscopy (EDS) and secondary ion mass spectrometry (SIMS) to provide information on surface concentrations. These data indicated that the uptake of Pb is relatively homogenous across the cement surface with no sites with much higher concentration observed. This suggests that lead is primarily uptaken into the calcium silicate hydrate (C – S – H) gel since this is the most abundant phase in the cement. In addition localized and unique crystal clusters were also observed on samples exposed to higher concentrations of Pb in solution.

The results indicate that a number of previous studies where the Pb was introduced during cement hydration and where Pb was found not to be released significantly are misleading from a geological waste repository perspective where the Pb will only come in contact with the cement after hydration is completed.

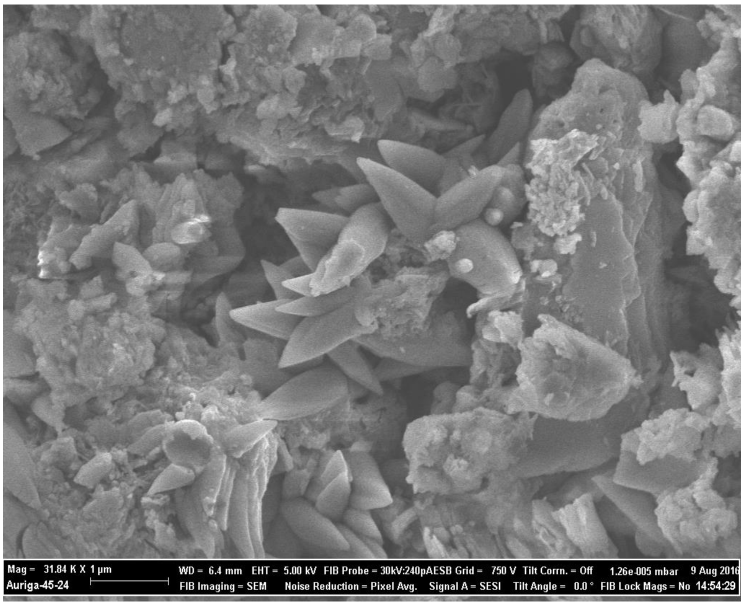


Figure 16. *SEM figure displaying unique crystal cluster formed on the NVRB cement sample exposed to Pb.*

- **Name: Dimitri Pletser**
  Project title: Low Temperature Immobilisation of Spent Adsorbents from Fukushima.
  Supervisors: Prof Bill Lee and Dr Luc Vandeperre.
  Sponsor: Hitachi Ltd.

The clean-up of the Fukushima Daiichi site continues to generate large volumes of spent adsorbents which need to be disposed of permanently. One of the candidates is a low temperature immobilisation process to avoid volatilising radioactive Cs and Sr species. Detailed radionuclide volatilisation experiments were performed at Hitachi Research Laboratories in Japan, to investigate possible Cs volatilisation behaviour from commercial zeolitic adsorbents. Cs volatilisation was shown to be negligible, in most cases below detection limits, at temperatures below 600ºC, with volatilisation starting at 700 ºC and strongly increasing above 800ºC.

To minimise Cs loss in the final waste treatment an immobilisation process with a maximum temperature of 600ºC was developed by sintering model waste with glass frit to form a dense Glass Composite Material (GCM) wasteform. A zeolitic model wasteform, chabazite, was loaded with between 8-12 wt % Cs waste loading and was sintered with two lead-based glass compositions, lead borosilicate (PBS) and a lead borate (PB) glass composition, at a maximum temperature of 600ºC.

Full encapsulation of the zeolitic model wasteform was achieved for waste loadings up to 50 wt.% in PBS and 40 wt.% in PB in all cases, with both GCM systems showing dense microstructures. PBS GCM formation was successful at a maximum of 500ºC, while the PB GCM formation was shown to be possible at a maximum temperature of 400ºC. Sintering optimisation undertaken has shown that the microstructure of the final wasteform can be finely tuned by controlling composition, sintering profiles and thermal treatment regimes. Sintering behaviour was shown to be independent of Cs waste loading of the adsorbent, but was shown to be strongly influenced by thermal treatment of the wasteform during sintering.

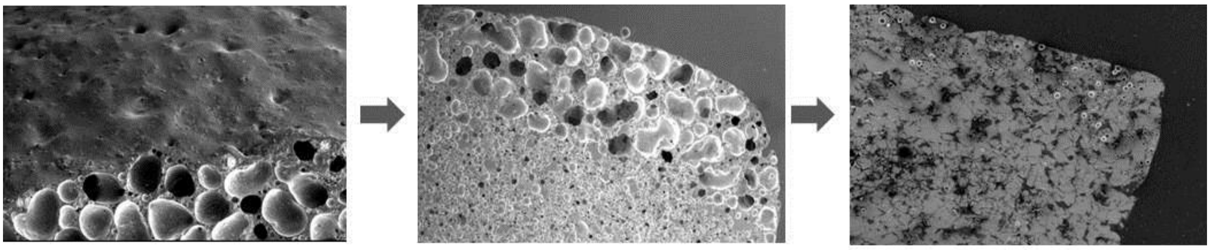


Figure 17. *Cross-sectional SEM images of PBS wasteforms. Show the progressive densification of three generations of wasteforms with increasingly optimised sintering profiles*

- **Name: Giorgio Sernicola**

  Project title: Developing small scale fracture tests for polycrystalline diamond.
  Supervisors: Dr Finn Giuliani and Dr T. Ben Britton.
  Sponsor: Element Six.

Polycrystalline diamond composites (PCD) were first sintered in the 1970s following research efforts focused on producing new, more durable materials to use as cutting tools. These composites are characterised by a complex microstructure composed of two stark different phases, hard and brittle diamond grains and a network of softer and ductile cobalt. Given the high volume fraction of brittle phase, life of these tools is dominated by their fracture behaviour and catastrophic failures that still represent the major issue for their application.

In the last three decades, improvements of the fracture properties of brittle materials have been sought through the development of new insights on toughening mechanisms, typically involving microstructure control that focuses on crack deflection at grain boundaries and interfaces. However, these are often difficult to engineer, as changing microstructural processing (e.g. through heat treatment, chemistry or powder processing) does not result in a one-to-one correlation with performance, since the influence of microstructure on crack path is varied and complex. Recent developments on characterisation at the micro-scale therefore present an opportunity to broaden our understanding of the role of individual factors on the bulk performance.

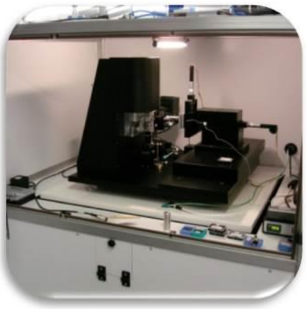
To investigate the fracture properties of individual features (i.e. individual crystallographic planes, grain boundaries or interfaces), we developed an innovative testing method. This approach is based on the double cantilever wedging to measure the fracture energy evolution with crack during stable growth and was successfully applied at the micron scale inside a SEM. Direct view of the crack growth in our sample and measurement of the energy absorbed during fracture, without use of load-displacement data, is afforded through the combination of a stable test geometry with an image based analysis strategy.

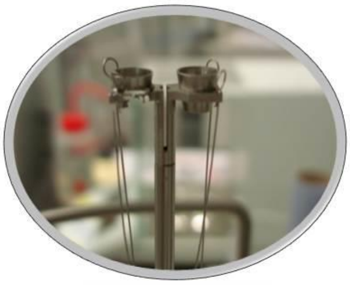
In addition to these tests, we have targeted characterisation at the role of microstructure on crack paths in polycrystalline diamond. Our focus has been on using high angular resolution EBSD combined with microindentation, to correlate intra-granular residual stresses gradients, due to thermal expansion mismatches, to crack deflection. It was found that the crack can follow the grain boundaries if grains are small but tends to deviate along (111) in coarse grains, yet stress gradients disrupt homogeneity of individual grains and are able to deflect the crack.
Exploitation of these novel techniques allows us to gather new insights on the mechanical properties of advanced ceramics that can usher in a new way of engineering the microstructure to obtain tougher ceramics.

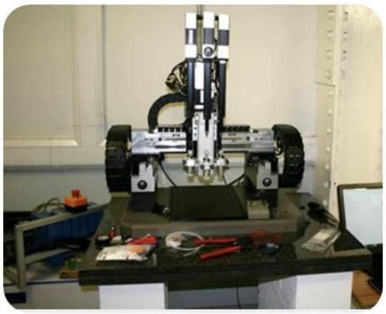
- **Name: Jia Hui Teo**
  Project title: Designing Ceramic Matrix Composites for Ceramic Armour.
  Supervisors: Dr Luc Vandeperre and Prof Eduardo Saiz.
  Sponsor: DSO National Laboratories.

Ceramics are hard materials, which makes them ideal for armour but their brittleness and weakness in tension is detrimental to performance. It is generally understood that impedance mismatches are bad for any armour systems as they are points of reflection, generating tensile stress waves which should be avoided. In this work, varying microstructures will be created using materials with different impedances to understand the reflection of waves at such interfaces on the microstructural level. Consequently, a better understanding of how the microstructures can be tailored to create materials that are able to reflect compressive waves progressively across the entire thickness instead of generating a large tensile wave at the rear end of the ceramic which will likely cause the ceramic to shatter. Delaying the failure of the ceramic gives it more time to defeat the ceramic, allowing sustained projectile erosion which could help improve the ballistic performance of the ceramic.

CAPABILITIES AND FACILITIES





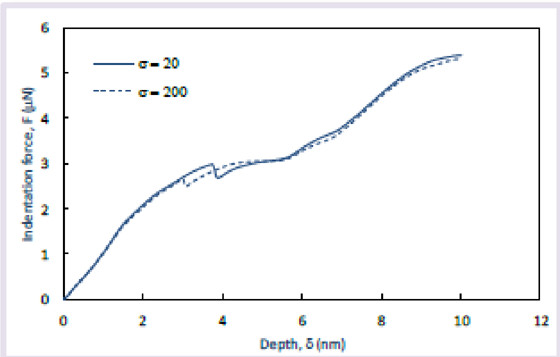


Although the purchasing and installation of large pieces of equipment by the Centre using the funding from the original CASC project is now completed, we continue to improve our experimental capability in this area using funds from other sources.

All equipment is available to the UK ceramics community. Here you will find a list of some of the equipment that we have, and if you wish to use any of these facilities, or have any question, please contact Garry Stakalls (g.stakalls@imperial.ac.uk, 020 7594 6770).

Nano-indenter

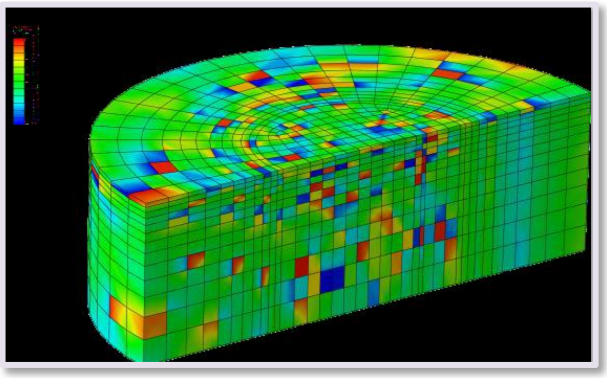
The high temperature nano-indenter, manufactured by Micro Materials, is located in the Structural Ceramics laboratory, on the basement of the Royal School of Mines (RSM), taking advantage of the better control of air, temperature and the reduced vibration levels.
As well as being fully instrumented, the nano-indenter operates at temperatures up to 750°C.



Usage of the nano-indenter is high, and results obtained have been reported at international meetings including the Fall MRS conference (Boston), the American Ceramics Society meeting (Daytona Beach) and at the ICMCTF (San Diego).

Nanoindenter available at CASC

Server



CASC's multiprocessor server allows to solve complex and node rich finite element simulations, such as a crystal plasticity simulation including soft and hard slip systems in MgO. Three dimensional crystal plasticity simulations are being carried out using parallel processing on the CASC cluster. It has been used to simulate the relation between primary and secondary slip systems activation and hysteresis, and the softening observed in the indentation force displacement response. A normal random distribution of the critical resolved shear stress results in a lower drop in the indentation force. This was used to study the relation between the change in the slope of the loading curve (corresponding to the activation of the secondary slip systems) and the spacing of hysteresis loops observed in the experimental data.

Freezer dryer

Freeze-drying is a drying process, where the solvent (normally water) is eliminated from the sample via direct sublimation from solid to gas phase. This is a useful way of eliminating solvents by keeping the material structure intact for further processing, like for example sintering.

We currently use this process for drying freeze-cast materials like alumina, zirconia, zeolites and graphene oxide.

Freeze dryer at CASC laboratory

Thermodynamic software

We purchased the FactSage version 6.1 from GIT Technologies, together with three substance databases.

A multi-user license for phase equilibria software has also been purchased from the American Society. This thermodynamic calculation software is available over the network to anyone in the CASC offices and has been applied to a range of projects including Si-stabilised B_4C and high temperature annealing of TiAlN, thermal treatments of high alumina castable refractories and producing composites of B_4C and SiC.

Thermal analysis

A suite of high-temperature thermal analysis equipment from Netzsch was installed in the Department of Materials, in a basement room that was converted specifically for this use. The equipment comprises:

- Dilatometer (thermal expansivity) up to 2400^{o}C.
- Simultaneous TG-DTA up to 2000^{o}C.
- Laserflash (thermal diffusivity) up to 2000^{o}C.

Crucibles of the high temperature combined TGA DTA

Netzsch have provided multiple training sessions, and all three items of the equipment are up and running.
The facility is heavily used and has a high usage by external users.
The **dilatometer** has two set-ups:

1. An alumina tube and pushrod for measurements up to 1600^{o}C.
2. A graphite set-up for measurements up to 2400^{o}C.

In-house developments in the past year have made it possible to use the dilatometer for hardness measurements and even creep measurements test have been done. Examples of CASC projects using the dilatometer are the measurement of the thermal expansion of refractory materials to estimate the risk of thermal shock damage, the characterisation of a wide range of ultra-high temperature ceramics, the study of mullite sintering and the analysis of residual stresses in mullite zirconia composites, hardness measurements of ZrB_2 and Al_2O_3 and the analysis of cracking due to shrinkage in geopolymers and sintering of silicon carbide-boron carbide composites.

Induction-heated thermo-mechanical test rig

The **combined TGA-DTA** has been used to quantify mass loss during drying of geopolymers, to analyse the decomposition of magnesium phosphate and magnesium silicate cements for nuclear waste treatment, to study silicon carbide or mullite sintering, to perform analysis of UHTC oxidation, to determine carbon yield from various ceramic additives and for characterisation of raw materials in general. Usage for third parties included work with Professor Jon Binnner (Birmingham University), Loughborough University, and Dr Bai Cui (University of Illinois), as well as characterisation of derivative products from commercial paper mills and work with Morgan Technical Ceramics.

The equipment to measure **thermal diffusivity via laser flash** has been extensively used to characterise a wide range of ultra-high temperature ceramics and carbon-ceramic composites as well as in collaborations with Rolls Royce, Morgan Technical Ceramics and Professor Mike Reece at Queen Mary College (thermo-electric materials).

An additional set up has been installed with the TG/DTA analyser to measure the specific heat capacity. This year we improved the ranged of the merasurement up to 1650 ^oC thanks to a high accuracy rhodium furnace.

Thermo-mechanical testing

The high temperature mechanical testing equipment from Instron is located in the Mechanical Engineering Department. One frame incorporates a vacuum system and a furnace from Materials Research Furnaces with a maximum temperature of 2000^oC, the second frame has induction heating up to 1200^oC.

The equipment is used in work with diverse industrial partners such as Seco Tools AB (Sweden) and for projects like “Turning waste from steel industry into valuable low cost feedstock for energy intensive industry” (RESLAG). In the last years, it has been used for a range of projects including measuring the properties of commercial cutting tools near the service temperature, studying mullite creep, and measuring high temperature strength of UHTCS’s and commercial refractories.

Vacuum hot press

The vacuum hot press from FCT Systems is fully operational.

The press operates at temperatures up to 2400^{o}C for sintering and 2100^{o}C for hot pressing with a maximum force of 250 KN, and can be used at atmospheric pressure or under vacuum. Large samples can be fabricated, as dies with diameters as large as 8 cm can be used.

Its use in CASC projects includes the preparation of a wide range of materials such as silicon carbide, boron carbide and composites, aluminium nitride alloys, zirconium carbide, tantalum and hafnium carbide, joining of UHTC's, glass ceramic-SiC composites, ultra-light SiC structures and mullite.

Its unique high-temperature capability has enabled the fabrication of a solid solution phase of HfC and TaC, which lead to a best poster prize at the ECI conference on ultra-high temperature ceramics at Hernstein, Austria.

It is also used by other university groups to perform tests on forging of functional ceramics for Professor Alford (Imperial College London) and for treatment of UHTC precursors for Professor Binner (Loughborough University).

Vacuum furnace

The vacuum furnace can be used to heat up a volume of 5 cm in diameter and 15 cm tall to temperatures up to 2500^{o}C, under vacuum or under a mixture of gasses.

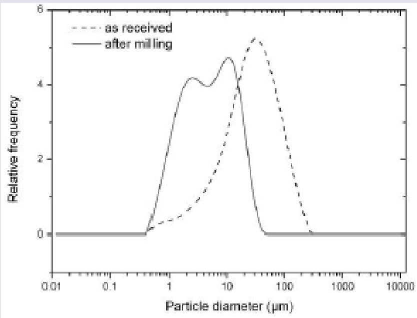
Opposed viewing ports allow observation of the sample during heating, and a sample elevator and cooling chamber allows for exchange of samples whilst the furnace is at temperature. The equipment has been used in the sintering of ceramics and metal-ceramic composites as well as for the analysis of glass and metal wetting on ceramic substrates.

Wet grinding mills

We purchased and installed a wet grinding mill capable of low-amplitude grinding of up to 5kg of ceramics in five different chambers and a ball rolling mill for homogenisation of suspensions and breaking up of agglomerates before processing.

Particle Size Analyser

The Department of Materials provided funds to acquire a laser particle size analyser. The equipment is able to determine size distribution using scattering of light by particles in dilute solutions and has the ability to measure particles with diameters ranging from 10^{-2} to 10^{-4} µm without changing any optics.



Examples of powder particles = distributions

High Temperature elastic properties by impulse excitation


Figure Set-up for room temperature measurements.

In 2013 we installed a piece of equipment to determine the Young and shear modulus as well as the Poisson's ratio for different materials. The measurement principle is based on the relationship between shape, density and stiffness and the natural vibration frequencies of a sample.
For example, to determine the Young modulus, typically a bending vibration mode is excited by hitting a sample supported on the nodes of the vibration with a small projectile in the centre. The resulting vibration is picked up with a microphone and analysis of this signal using the Fourier transformation yields the frequency of the vibration.
The software also analyses the decay in amplitude of the vibration with time to determine a value for the damping of the vibration.

The model installed at CASC comes with a furnace capable of operating to 1750^{o}C in air or inert atmosphere. Hardware and software enables fully automated excitation and measurement, making it possible to investigate the variation of the elastic properties with temperature, the hopping of oxygen vacancies bound to dopants in response to stress at low temperature in doped zirconia, and the softening of grain boundary glassy phases in sintered silicon nitride.

3D Printer

Another important piece of equipment at CASC is a robotic assisted deposition system from 3D Inks (USA). This system can print 3D structures using continues extrusion. The movement of the printing head can be controlled, with submicron precision. The printer allows the combination of three different inks to fabricate multiphase structures.

In addition to this one, this year, a new 3D printer was purchased, a Micro Plus 3D printer from EnvisionTEC. This piece of equipment can produce functional parts with exceptional surface quality without sacrificing speed. The materials available for the Micro Plus line cover a wide range of applications, including jewellery, toy, medical, industrial design, engineering, and more.

Laboratory Mixing Extruder (LME)

The Dynisco Polymer Test LME Laboratory Mixing Extruder can be used to evaluate the processability of a variety of plastics and rubbers prior to production. From very fine powders to coarse materials, the LME will meet many extruding needs. It possesses a moveable header and dial gage that allows for constant mixer adjustability and allows for various extrudate mix levels in a single sample run. It can be used in the production of polymer blends or alloys. Mixing may be independently adjusted such that agglomerates of additives, such as fillers or pigments, may be accurately controlled.

It is a three-part system: Extruder with Take Up, and Chopper Accessories. Maximum temperature 400°C and Variable speed control, 5 to 260rpm.

Optical Microscope Axio Scope A1

Optical microscope with reflected and transmitted light, bright and dark field, DIC, camera and software for image acquisition and analysis was also installed in 2013.
The microscope has a modular design that facilitates the installation for different set-ups to allow *in-situ* experiments like mechanical testing or freezing of colloids.

Rapid prototype (CNC) milling machine

Rapid prototyping is the dramatically transformation of a design and manufacturing processes of a physical part. This milling machine has answered the call for a cost-effective, high precision and compact solution.

It is used to create realistic models, functional prototypes and moulds and is compatible with a wide range of materials. It is able to produce highly accurate parts including those for complex snap-fits from an extensive range of non-proprietary materials including Acetal, ABS, chemical woods, acrylic, plaster, nylon, styrene and many medical grade materials including PEEK.

It offers a number of significant advantages over additive rapid prototyping (ARP) or "3D orienting" systems, making a combination of the two technologies the perfect prototyping solution.

Elemental Mass Gas Analyser

An Oxygen-Nitrogen-Hydrogen Elemental Mass Gas Analyser (Horiba, EMGA – 830 series) was installed at CASC in 2015.

This includes also the Carbon-Sulphur Elemental Mass Induction Analyser (EMIA series) and a Glow Discharge-Optical Emission Spectroscopy (GD-OES) setup.

Graphene reactor

A one of a kind modular system for large-scale synthesis of chemically modified graphene, based on chemical graphite exfoliation, is in use. This system is flexible and allows for "on demand" fabrication of materials with tailored properties.

The rig consists of two jacketed glass reactors of up to 5L mounted on a bench standing framework (*Radleys, Essex, UK*). Overhead stirrers (*Heidolph*) with PTFE propeller stirring paddles placed at different heights ensured vigorous mixing in the reactors. Oil in jackets is connected to a *Huber Unistat* recirculating chiller.

The manipulation of liquids (e.g. addition of concentrated acids or transfer of slurry between vessels) is carried out using a software controlled peristaltic pump with acid resistant tubing (Marprene).
AVA software allows for online control of the temperature in the jacket oil, or the reacting mixture, mas addition and stirring. The component parts of the system are a computer controlled reactor system with two chambers to perform the chemical exfoliation of graphite at controlled temperature, stirring speed… and a purification system based on centrifugation at controlled temperature.

This unique modular approach allows us the flexibility to synthesize materials on demand for different applications.

Micromechanical Tester

This year CASC purchased a Microtest In-Situ Stage from GATAN, the Mtest300.
The tensile/compression/bending stage is primarily design to be used within the confined space of an SEM chamber, although it can be used with optical microscopes, AFM and X-Ray Diffraction machines.

The module allows different materials to be deformed and stretched at loads up to 300N, providing a deeper understanding into what causes the deformation; and the ability to image where the microstructure change is occurring.

Other equipment

Other equipment like a new cutting machine and a glove box were installed.

CASC RESEARCH PORTFOLIO

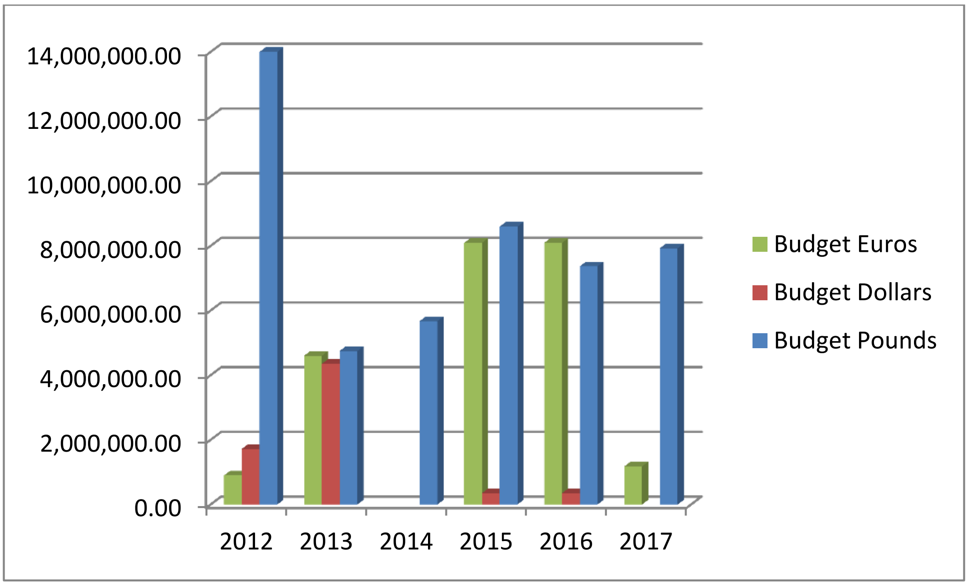


Figure 18. Funded proposals, over the last 6 years

Current Projects (Jan-Dec: 2017)

- **Materials Systems for Extreme Environments.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2013-2018.
  Budget (£): 3,723,651

- **Engineering with Graphene for Multi-Functional Coatings and Fibre-Composites.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2013-2017.
  Budget (£): 286,893.

- **Graphene-Three Dimensional Networks.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2013-2017.
  Budget (£): 1,257,620.

- **Wound Care Materials.**
  Funder: Welland Medical.
  Project start and end date: 2014-2017.
  Budget (£): 41,766.

- **Graphene-Based Composites for Pipeline Liners.**
  Funder: Petronas Research Sdn Bhd.
  Project start and end date: 2014-2017.
  Budget (£): 479,863.

- **Carbides for Future Fission Environments (CAFFE).**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2015-2019.
  Budget (£): 437,733.

- **RESLAG: Turning Waste from Steel Industry into Valuable Low Cost Feedstock for Energy Intensive Industry.**
  Funder: European Commission.
  Project start and end date: 2015-2019.
  Budget (€): 8,092,712, but £300,000 to Imperial.

- **Advanced Waste Management Strategies for High Dose Spent Adsorbents.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2015-2018.
  Budget (£): 191,687.

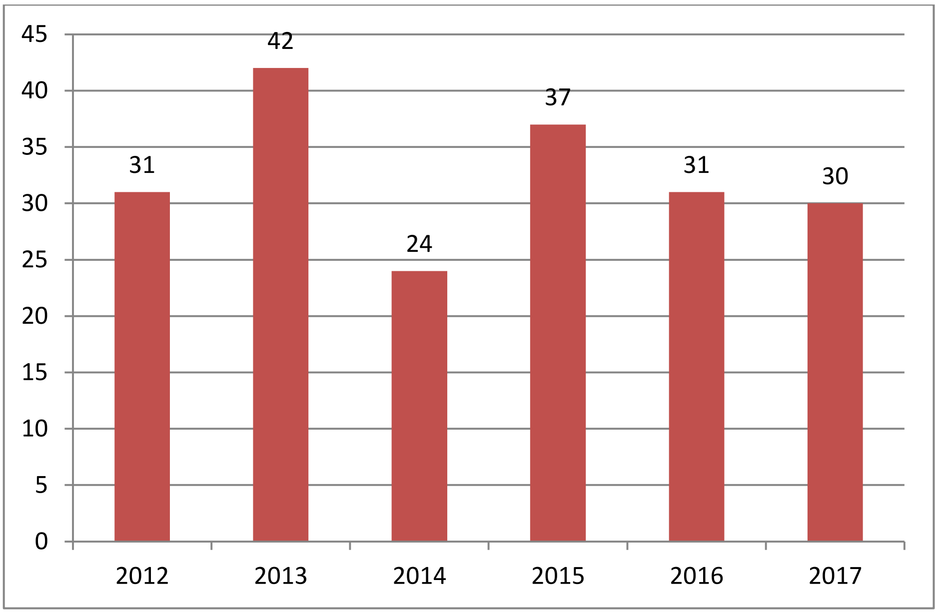
- **High Emissivity Coatings for Furnace Linings.**
  Funder: SCG Thailand.
  Project start and end date: 2015-2018.
  Budget (£): 497,381.

- **Ceramic Armour from Rice Husk Ash.**
  Funder: DSTL.
  Project start date: 2016-2018.
  Budget (£): 260,000.

- **Transpiration Cooling Systems for Jet Engine Turbines and Hypersonic Flight.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2016-2021.
  Budget (£): 1,000,000.

- **MAPP: EPSRC Future Manufacturing Hub in Manufacture using Advanced Powder Processes.**
  Funder: Engineering and Physical Science Research Council (EPSRC).
  Project start and end date: 2017-2023.
  Budget (£): 10,000,000, but £750,000 to CASC.

- **AMITIE: Additive Manufacturing Initiative for Transnational Innovation in Europe.**
  Funder: European Commission.
  Project start and end date: 2017-2021.
  Budget (€): 877,500.



CASC's number of publications over the last 6 years

Publications: Journal Papers (Jan-Dec: 2017)

1. *Experimental synthesis and DFT investigation of radiation tolerance of $Zr_3(Al_{1-x},Si_x)C_2$ MAX phases.* W.E. Lee, N. Ni, E. Zapata-Solvas. Journal of the American Ceramic Society, **100**, (4), p: 1377-1387, 2017.
2. *Complex ceramic architectures by directed assembly of "responsive" particles*. E. Garcia-Tunon, G. C. Machado, M. Schneider, S. Barg, R. V. Bell, E. Saiz, Journal of the European Ceramic Society, **37**, (1), p: 199-211, 2017.
3. *High*-temperature fracture toughness of mullite with monoclinic zirconia. D. Glymond, M. J. Vick, F. Giuliani, L. J. Vandeperre. Journal of the American Ceramic Society, **100** (5), p: 1570-1577, 2017.
4. *Micromechanical strength of individual Al_2O_3 platelets*. E. Feilden, T.Giovannini, N.Ni, C.Ferraro, E.Saiz, L. Vandeperre,F.Giuliani. Scripta Materialia., **131**, p: 55-58, 2017.
5. *Using graphene networks to build bioinspired self-monitoring ceramics*. O.T. Picot, V.G.Rocha, C.Ferraro, N.Ni, E.D'Elia, S.Meille, J.Chevalier, T. Saunders, T.Pejis, M.J.Reece, E. Saiz. Nature Communications, **8**, 14425, 2017.
6. *Water vapour corrosion of rare earth monosilicates for environmental barrier coating* application. N. Al Nasiri, N.Patra, D.D. Jayaseelan, W.E. Lee. Ceramics International, **43**, p: 79393-7400, 2017.
7. *A facile way to produce epoxy nanocomposites having excellent thermal conductivity with low contents of reduced graphene oxide*. G.B. Olowojoba, S. Kopsidas, S. Eslava, E. Saiz, A.J. Kinloch, C. Mattevi, V.G. Rocha, A.C. Taylor. Journal of Material Science, **52** (12), p: 7323-7344, 2017.

8. *Oxidation resistant tungsten carbide hardmetals*. S.A. Humphry-Baker, K. Peng, W.E Lee. International Journal of Refractory Metals and Hard Materials, **66**, p: 135-143, 2017.
9. *Mechanical and biological evaluation of 3D printed 10CeTZP-Al_2O_3 structures*. L.Goyos-Ball, E. García-Tunon, E. Fernandez-Garcia, R. Diaz, A. Fernandez, C. Prado, E. Saiz, R. Torrecillas. Journal of the European Ceramic Society, **37**, p: 3151-3158, 2017.
10. *Elastic properties, thermal stability, and thermodynamic parameters of MoAlB*. S. Kota, M. Agne, E. Zapata-Solvas, O. Dezellus, D. Lopez, B. Gardiola, M. Radovic, M. W. Barsoum. Physical Review B, **95**, 144108, 2017.
11. *Spontaneous solid-state foaming of nanocrystalline thermoelectric compounds at elevated temperatures*. S. Humphry-Baker, C.A. Schuh, Nano Energy, **36**, p: 223-232, 2017.
12. *A unifying scaling for the Bauschinger effect in highly confined thin films: a discrete dislocation plasticity study*. S. Waheed, R. Hao, A. Bhowmik, D.S. Balint, F. Giuliani. IOP science. Modelling and Simulation in Materials Science and Engineering 25, 054003, 2017.
13. *Osseous differentiation on freeze casted 10CeTZP-Al_2O_3 structures*. L. Goyos-Ball, E. Fernández, R. Díaz, A. Fernández, C. Prado, R. Torrecillas, E. Saiz. Journal of the European Ceramic Society, **37** (15), p: 5009-5016, 2017.
14. *Densification behaviour and physico-mechanical properties of porcelains prepared using spark plasma sintering*. W. Lerdprom, S. Grasso, D.D. Jayaseelan, M.J. Reece, W. E. Lee. Advances in Applied Ceramics, **116** (6), p: 307-315, 2017.
15. *Synthesis and physical properties of $(Zr_{1-x}Ti_x)_3AlC_2$ MAX phases*. E. Zapata-Solvas, M.A. Hadi, D. Horlait, D.C. Parfitt, A. Thubaud, A. Chroneos, W.E. Lee. Journal of the American Ceramic Society, **100** (8), p: 3393-3401, 2017.
16. Robust Bioinspired Graphene Film via π–π Cross-linking. H. Ni, F. Xu, A. P. Tomsia, E. Saiz, L. Jiang, Q. Cheng, ACS Applied Materials and Interfaces, 9 (29), p: 24987-24992, 2017.
17. *Oxidation of UC: An in situ high temperature environmental scanning electron microscopy study*. C. Gasparrini, R. Podor, D. Horlait, M.J.D. Rushton, O. Fiquet, W.E. Lee. Journal of Nuclear Materials, 494, p: 127-137, 2017.
18. *The role of ceramic and glass science research in meeting societal challenges: Report from an NSF-sponsored workshop*. K.T Faber et al. Journal of the American Ceramic Society, **100** (5), p: 1777-1803, 2017.
19. *Laves phase intermetallic matrix composite in situ toughened by ductile precipitates*. A. J. Knowlesa, A.Bhowmik, S. Purkayastha, N. G Jones, F. Giuliani, W. J. Clegg, D. Dye, H. J. Stone. Scripta Materialia, **140**, p: 59-62, 2017.
20. *A new beta titanium alloy system reinforced with superlattice intermetallic precipitates*. A. J. Knowles, T-S June, A. Bhowmik, N. G. Jones, T. B. Britton, F. Giuliani, H. J. Stone, D. Dye. Scripta Materialia, **140**, p: 71-75, 2017.
21. *In situ stable crack growth at the micron scale*. G. Sernicola, T. Giovannini, P. Patel, J. R. Kermode, D.S. Balint, T.B. Britton, F. Giuliani. Nature Communications, 8:108, 2017.
22. *Production and Reliability Oriented SOFC Cell and Stack Design*. M. Hauth, V. Lawlor, P. Cartellieri, C. Zechmeister, S. Wolff, C. Bucher, J. Malzbender, J. Wei, A. Weber, G. Tsotridis, H. L. Frandsen, K. Kwok, T. T. Molla, Z. Wuillemin, J.V. Herle, F. Greco, T. Cornu, A. Nakajo, A. Atkinson, L. Vandeperre, X. Wang. ECS Transactions, **78** (1), p: 2231-2249, 2017.
23. *Density functional theory insights into ternary layered boride MoAlB*. Y. Bai, X.Qi, A.Duff, N. Li, F. Kong, X. He, R. Wang, W. E. Lee. Acta Materialia, **132**, p: 69-81, 2017.
24. *Impact of microwave processing on porcelain microstructure*. W. Lerdprom, E. Zapata-Solvas, D. D. Jayaseelan, A. Borrell, M.D. Salvador, W.E. Lee. Ceramics International, **43** (16), p: 13765-13771, 2017.

25. *Graphene Oxide: An All-in-One Processing Additive for 3D Printing*. E. García-Tuñón, E. Feilden, H. Zheng, E. D'Elia, A. Leong, E. Saiz. Applied materials & Interfaces, **9** (38), p: 32977-32989, 2017.
26. *Multimaterial 3D Printing of Graphene-Based Electrodes for Electrochemical Energy Storage Using Thermoresponsive Inks.* V.G.Rocha, E. García-Tuñón, C. Botas, F. Markoulidis, E. Feilden, E. D'Elia, N. Ni, M. Shaffer, E. Saiz. ACS Applied Materials & Interfaces, **9** (42), p: 37136-37145, 2017.
27. *3D Printing Bioinspired Ceramic Composites*. E. Feilden, C. Ferraro, Q. Zhang, E. García-Tuñón, E. D'Elia, F. Giuliani, L. Vandeperre, E. Saiz. Scientific Reports, **7**, 13759, 2017.
28. *Data on a Laves phase intermetallic matrix composite in situ toughened by ductile precipitates*. A. Knowles, A. Bhowmik, S. Purkayastha, N. G. Jones, F. Giuliani, W. J. Clegg, D. Dye, H. J. Stone. Data in Brief, **14**, p: 489-493, 2017.
29. *Microindentation – a tool for measuring cortical bone stiffness?* M. Arnold, S. Zhao, S. Ma, F. Giuliani, U. Hansen, J. P. Cobb, R. L. Abel, O. Boughton. Bone Joint Research, **6**, p: 542-549, 2017.

In Press

1. Nacre-like ceramic refractories for high temperature applications. P. I.B.G.B. Pelissari, F. Bouville, V. C. Pandolfelli, D. Carnelli, F. Giuliani, A. P. Luz, E. Saiz, A. R. Studart. Journal of the European Ceramic Society, Just Accepted.

OUTREACH

Newsletters

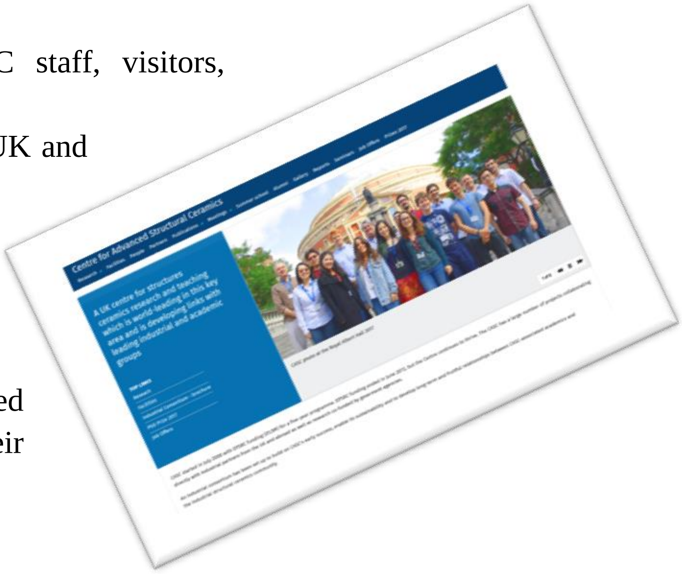
CASC's newsletters, together with the annual report, provides news and contact information for visitors to the Centre, together with dissemination at meetings and international visits.

Two newsletter have been circulated in 2017 (June and December), covering new CASC research, visitors to the Centre, PhD thesis defences, the sixth CASC Industry Day, the Sir Richard Brook Prize and the Seventh edition of CASC Summer School, as well as prizes received by different CASC members and media mentions.

Here you can find June's and December's Newsletter.

Latest news on our activities can also be found through our twitter account (@Casc_Imperial).

Website



Our website contains details of CASC staff, visitors, equipment and activities.

Meeting organised by CASC, as well as future UK and international ceramic-related meetings are also advertised on this website.

Previous annual reports and other publicity material are available for downloading.

The website is continually being updated with new information about CASC staff and their research activities and presentations.

Sir Richard Brook Prize

In 2010, CASC set up the Professor Sir Richard Brook Prize for the best ceramics PhD thesis in the UK, with sponsorship from Morgan Advanced Materials.

This prize aims to increase the sense of community amongst PhD students researching ceramics in the UK, and to mirror the IOMMM's AT Green Award that is available to undergraduates.

The 2016 prize was won by Dr Claudio Ferraro, from Imperial College London. The title of his thesis is *"Bio-inspired ceramic based composites."* and was supervised by Prof Eduardo Saiz.

The award in general covers a certificate, plaque and £1000 cheque.

The 2017 nominations are closed and the winner will shortly be announced.

CASC Industry Day

The sixth CASC Industry Day was held on the 20th of January 2017 at Imperial College with different attendees from Industry (Morgan Advanced Materials, John Crane, SAFRAN, SECO, Asahi, DSTL, Reaction Engines and AMRICC) and University.
The industry day was followed with the Steering Group meeting in the afternoon.

The aim is to continue CASC activities and strengthen our relationship to industry.

In 2018, the meeting took place the 12th of January.

CASC | Imperial College London

CASC Industry Day 20 January 2017
Programme

58 Prince's Gate | South Kensington Campus | London SW7 2PG
Imperial College London
10:00 am – 2:00 pm
Imperial College London

10:00 – 10:15	**Coffee**
10:15 – 10:30	**CASC – Industrial Consortium.** **Introduction** - ***Professor Eduardo Saiz***
10:30 – 12:30	**Research in progress & Technical capabilities.** ***Mr. Ezra Feilden-Irving, ICL*** - *Additive manufacturing of UHTCs and CMCs.* ***Dr. Cathryn Hickey, AMRICC*** - *AMRICC and Imperial College.* ***Dr. Alan McLelland, Morgan Advanced Materials*** - *Morgan and its collaboration with academia.* ***Dr. Eugenio Zapata-Solvas, ICL*** - *Challenges for MAX Phase ceramics on future fission reactors.* ***Dr. Esther Garcia-Tuñon Blanca, ICL*** - *Water based building blocks for robocasting.* ***Dr. Ayan Bhowmik, ICL*** - *Using in-situ microLaue diffraction to study deformation micromechanisms of brittle materials.*
12:30-1:00	**Open Discussion.**
1:00 – 2:00	**Lunch.**

CASC Summer School on Ceramics

The 8th edition of the Ceramic Summer School was held during the 13th, 14th and 15th of September 2017, at Imperial College London.

The meeting started on Wednesday with **Professor Eduardo Saiz** giving an introduction to *Ceramic Shaping*. This was followed by a talk from **Dr Alan Porporati** from **Ceramtec** on *Ceramics in Arthroplasty*. He talked about the development of ZPTA ceramics over the last 14 years and what is the future for such ceramics. We also had **Dr Andre Prette,** from **Lucideon**, that took us through the history of *flash sintering of ceramics*, from its origin until today. To end the day, **Dr Finn Giuliani** gave an *introduction to mechanical properties*, which were used during the lab sessions of Thursday.

Thursday opened with a masterclass on *additive manufacturing* by **Dr Fabrice Rossignol** from the **University of Limoges (France)**, and after coffee we had **Dr Nasrin Al Nasiri,** from **Imperial College**, talking about *Ceramic Matrix Composites*; her work is done in collaboration with Rolls Royce.

After lunch, there were different lab sessions that were related to the master classes from the previous day. One of them was focused on 3D printing, while the other was on ceramic powder processing and shaping.

Lab sessions during the Summer School

Finally on Friday, **Dr Alan McLelland (Morgan Advanced Materials)** took us through the *future of ceramics from a company point of view*. And to finish the day we had the masterclass from **Dr Esther Garcia (Liverpool University)** on *rheology for additive manufacturing.*

The course was attended by a mix of people from industry (Morgan Advanced Materials, Saint Gobain, Rolls Royce, independent consultants) and academy (Imperial College, ETH, Queen Mary University).

The exact date and programme of the next edition will be published early in 2018, after input from our industrial consortium.

Meetings attended during 2017

- 41st International Conference and Expo on Advanced Ceramics and Composites, Daytona Beach, USA.
- 1st meeting of the UK Chapter of the American Ceramic Society, London, UK.
- Young Ceramists Additive Manufacturing Forum (yCAM), Berlin, Germany.
- RESLAG Project Meeting, Turku, Finland.
- 1 Day Research Meeting on Advanced Ceramics, London, UK.
- European Wound Management Association (EWMA 2017), Holland.
- 12th Pacific Rim Conference on Ceramics and Glass Technology, Hawaii, USA.
- 15th Conference & Exhibition of the European Ceramic Society, Budapest, Hungary.
- 7th International Conference on Nanoscience and Technology, Beijing, China.
- Ultra-High Temperature Ceramics: Materials for Extreme Environment Applications IV, Windsor, UK.
- MS&T 17, Pittsburgh, USA.
- RESLAG Project Meeting, Stuttgart, Germany.
- 6th International Conference on Electrophoretic Deposition: Fundamentals and Applications, South Korea.
- 10th International Conference on High Performance Ceramics, Nanchang, China.
- 2017 MRS Fall Meeting & Exhibit, Boston, USA.