The agreed collaboration between Imperial College London and Beijing Institute of Aeronautical Materials (BIAM) relates to promoting world leading research on materials characterisation, processing and modelling. This Centre involves both the Department of Mechanical Engineering and the Department of Materials at Imperial College London. The aim of this collaboration is to further improve safety, light-weighting and efficiency for the next generation of aircraft.

Centre Objectives

The agreed collaboration between Imperial College London and Beijing Institute of Aeronautical Materials (BIAM) relates to promoting world leading research on materials characterisation, processing and modelling. This Centre involves both the Department of Mechanical Engineering and the Department of Materials at Imperial College London. The aim of this collaboration is to further improve safety, light-weighting and efficiency for the next generation of aircraft.

Executive Summary

It has been a very challenging and productive year for us. Now four years after the establishment of the centre, ten PhDs and four RAs have carried out research in the BIAM centre and have been working closely with the twenty six visitors from BIAM on a wide variety of topics.

Two conference workshops were organised and attended by BIAM and Imperial College London researchers (May 2016 at BIAM, July 2016 at Imperial College London) and these have greatly helped to forge a close working partnership, together with a strong collaboration. This has resulted in innovative and novel research and initial findings can be found in the two sets of six-monthly reports produced by Imperial in March and September 2016 as well as journal and conference papers.

The College is very appreciative that BIAM has signed agreement to continue funding the Centre for Materials Characterisation, Processing and Modelling for a further five years after the current five year period. We look forward to building on our achievements going forward.

"...a very challenging and productive year..."
18 academic staff involved

Received 30+ visitors from AVIC

11 papers published
1 patent filed

7 research topics underway

Recruited 10 PhD students and 3 RAs

10 visiting academics hosted

15 six-monthly reports produced

2 workshops held

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Content

4 Structure of the Centre
5 Development plan of the Centre
5 List of research projects
6 Testimonials
7 Research project descriptions
10 Key equipment used by the Centre
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13 Imperial news & initiatives
The management and governance arrangements for the Centre are as follows

### Directors of the Centre
- Prof Jianguo Lin FREng – Director
- Prof John Dear – Executive Co-Director
- Prof Fionn Dunne FREng – Co-Director
- Prof Kamran Nikbin – Co-Director

### Steering Committee
Representatives of the Steering Committee review, discuss and make decisions in respect of the matters submitted by the Management Committee for their consideration and/or endorsement, including:

(i) formulate and approve the development plan of the Centre;
(ii) approval of annual project plans of the Centre;
(iii) seek additional funding resources [if required].

#### Membership
- **Prof Xinguo Zhang**
  Senior Vice President, AVIC
- **Prof Jeff Magee**
  FREng
  Dean, Faculty of Engineering
- **Prof Jinzhong Wei**
  Director, Technology and Information Department, AVIC
- **Prof Peter Cawley**
  FREng
  FRS
  Head of Department, Mechanical Engineering
- **Prof Shenglong Dai**
  President, BIAM
- **Prof Tony Kinloch**
  FREng
  FRS
  Professor of Adhesion, Mechanical Engineering
- **Prof Yajun Wang**
  Executive Vice President, BIAM
- **Prof Neil Alford**
  FREng
  Associate Provost (Academic Planning)

### Management Committee
The representatives of the Management Committee shall carry out, including:

(i) execute the annual project plans of the Centre;
(ii) monitor the quality, timely implementation and execution of approved Statements of Work;
(iii) consider any amendments to Statements of Work proposed by the Parties;
(iv) provide the Steering Committee with strategic management information;
(v) develop plans for seeking additional funding sources.

#### Membership
- **Prof Gang Chen**
  Deputy Director, Technology & IT, AVIC
- **Prof Jianguo Lin**
  FREng
  Head, Mechanics of Materials Division
- **Prof John Dear**
  Professor of Mechanical Engineering
- **Prof Guangxun Liu**
  Director, Int. Cooperation Dept, BIAM
- **Dr Dimitris Sarantaridis**
  Professor of Micromechanics, Materials
- **Ms Tian Tian**
  Project Mgr, Int. Cooperation Dept, BIAM
- **Dr Ming-So Pham**
  Dr Fionn Dunne
  Dr John Dear
  Senior Associate, Corporate Partnerships

### Other associated academic staff
- Dr Daniel Balint, Dr Ben Britton, Dr Maria Charalambides, Dr Catrin Davies, Prof Stephen Garwood (FREng), Prof Tony Kinloch (FRS, FREng), Prof Mike Lowe (FREng), Prof Barbara Shollock, Prof Gordon Williams (FRS, FREng), Dr Bamber Blackman, Dr Gregory Offer, Dr Min-Sho Pham, Dr Jun Jiang, Dr Zhusheng Shi

### RAs and PhDs in current year (supervisors in italics)
- **Dr Iman Mohagheghian** – Transparent Materials and Bird-Strike
  Prof John Dear & Prof Tony Kinloch
- **Dr Yi Wang** – Transparent Materials
  Prof Tony Kinloch & Prof John Dear
- **Prof Jianguo Lin & Dr Catrin Davies**
- **Jie Zhou** – Bird Strike for Transparent Materials
- **Dr Maria Charalambides & Prof John Dean**
- **Yi Wang (2)** – Modelling of Diffusion Bonding in Powder Forging
  Dr Daniel Balint & Prof Jianguo Lin
- **Muzi Li** – Effect of Cooling Rate on the Microstructure of Ni-base Superalloy
  Prof Barbara Shollock & Prof Fionn Dunne
- **Suki Adande** – Functionally Graded Engineering Superalloy
  Dr Ben Britton & Prof Fionn Dunne
- **Dr Yanju Wang** – Powder forging process and modelling
  Prof Jianguo Lin, Dr Daniel Balint, February 2016 (6 months)
- **Dr Qinyaing Yu** – Powder forging process and modelling
  Prof Jianguo Lin, Dr Daniel Balint, February 2016 (6 months)
- **Dr Mu Chen** – Characterisation and modelling of the flexible lithium battery
  Dr Gregory Offer, Prof John Dear, February 2016 (6 months)
- **Dr Jingyun Zhao** – Damage tolerance properties of the modern aircraft transparencies
  Dr Bamber Blackman, Prof John Dear, March 2016 (6 months)
- **Dr Wenying Xu** – Microstructure analysis and creep behaviour modelling of powder metallurgy superalloy
  Dr Min-Sho Pham, Dr Fionn Dunne, March 2016 (6 months)
- **Dr Liu Chen** – Computation and simulation of Ti alloy fatigue and creep behaviours
  Dr Min-Sho Pham, Dr Fionn Dunne, August 2016 (12 months)
- **Dr Fan Gao** – Hot deformation process and failure behaviours of gamma TiAl alloy
  Dr Jun Jiang, August 2016 (6 months)
- **Dr Weiming Liu** – Characterisation of the all solid state thin film lithium battery
  Dr Gregory Offer, Prof John Dear, November 2016 (6 months)
- **Dr Hongyan Liu** – Process and simulation of all solid state thin film lithium battery
  Dr Gregory Offer, Prof John Dear, November 2016 (6 months)

### BIAM Academic Visitors in current year
- **Dr Xiaofeng Zhang** – Characterisation and modelling of the flexible lithium battery
  Dr Gregory Offer, July 2015 (12 months)
- **Dr Yanju Wang** – Powder forging process and modelling
  Prof Jianguo Lin, Dr Daniel Balint, February 2016 (6 months)
- **Dr Qinyaing Yu** – Powder forging process and modelling
  Prof Jianguo Lin, Dr Daniel Balint, February 2016 (6 months)
- **Dr Mu Chen** – Characterisation and modelling of the flexible lithium battery
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  Dr Gregory Offer, Prof John Dear, November 2016 (6 months)
The plan is to provide for research as needed by BIAM. The research interests of BIAM are mostly centred on development of materials, manufacture and in service maintenance of aircraft structures. The mode of operation for planning future research in the Centre, is for BIAM staff to provide a brief on needed specific research. To be expected is that there will be visiting researchers from BIAM who will be assigned research in the BIAM Centre each of which will be associated with a specific research topic. The BIAM centre will allocate funding for a PhD or postdoctoral researcher to initiate and perform the research and work in association with the visiting academic from BIAM. This mode of operation should work well and it means that all BIAM visitors working in the College have PhD or post doctorate staff within the College to research in association with and this connection continues after the visiting academic returns to BIAM. The academic supervisor for the PhDs and post doctors is also the academic supervisor for the visiting academic. Examples of research topics are given below:

- **Powder forging**: A novel forming process is developed for superalloy powder metallurgy - Imperial: Dr Qian Bai, Mr Jiaying Jiang, Mr Yi Wang (2); Academic visitors: Dr Xiaoming Zhou, Prof Shuyun Wang, Dr Yunpeng Dong, Dr Shuang Fang, Dr Yanju Wang, Dr Qiuying Yu; Supervisor: Prof Jianguo Lin, Dr Daniel Balint, Dr Zhusheng Shi, Prof Jinwen Zou

- **Effect of cooling rate on precipitates in nickel superalloy**: characterisation of gamma and gamma prime distribution and development under different cooling rate and the correlation to high temperature creep performance – Imperial: Mr Muzi Li; Academic visitors: Dr Gaofeng Tian, Mr Zichao Peng; Supervisor: Prof Fionn Dunne, Prof Barbara Shollock

- **On the soft impact response of laminated glass at low and high velocity regimes** – Imperial: Dr Iman Mohagheghian, Mr Yi Wang, Mr Jie Zhou; Academic visitors: Dr Xintao Guo, Dr Xiaowen Zhang, Dr Liangbao Jiang; Supervisor: Prof John Dear, Prof Yue Yan

- **Transparent composites and bird strike**: Experimental and numerical investigation are conducted on impact of gelatine and rubber projectiles on the laminated glass windows – Imperial: Dr Iman Mohagheghian, Mr Jie Zhou; Supervisors: Prof John Dear, Dr Maria Charalambides, Prof Yue Yan

- **The micromechanical testing of engineering alloys**: performing in-situ micromechanical testing on FIB fabricated micro-pillars to quantify the performance of individual microstructural units – Imperial: Mr Suki Adande; Supervisor: Dr Ben Britton, Prof Fionn Dunne

- **Characterisation of all solid-state thin film lithium battery and battery thermal runaway modelling** – Imperial: Mr Yan Zhao; Academic visitors: Dr Xiaofeng Zhang, Dr Mu Chen, Dr Hongyan Liu, Dr Weiming Liu; Supervisor: Dr Gregory Offer, Prof John Dear, Prof Yue Yan

- **Optimisation of forming condition of TiAl alloy and simulations to its fatigue behaviour via CPFEM** – Academic visitors: Dr Fan Gao, Dr Liu Chen; Supervisors: Dr Jun Jiang & Dr Minh-son Pham

"The agreed collaboration... relates to promoting world leading research on materials characterisation, processing and modelling... for the next generation of aircraft."

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**List of research projects**

1. **Transparent Materials for Aircraft**
2. **Bird-strike on Laminated Glass Structures**
3. **Characterisation and Degradation of All Solid-State Thin Film Lithium Battery**
4. **Characterisation and Modelling of the Mechanical Properties of the Isolated Phases in γ/γ’ Microstructure**
5. **Investigating the Mechanical Stresses that Arise in a Functionally Graded Engineering Superalloy**
6. **Development of a Direct Powder Forging Process**
7. **Optimisation of forming condition of TiAl alloy and simulations to its fatigue behaviour via CPFEM**
Testimonials

Personal statements from research staff and students currently involved within the Centre.

“I would like to thank BIAM for providing this great opportunity for me to work at Imperial. During the past year, I had studied about the solid-state thin-film lithium battery in Dr Gregory Offer’s group ‘electrochemical science and engineering (ECSE)’. Within this vibrant group, I engaged in the study of the characterisation of thin-film lithium battery, including the conventional tool, such as electrochemical impedance spectroscopy, etc. Additionally, we had developed a combined apparatus including battery cycling, voltage measurement and temperature monitor & control, which could be employed to measure the entropy change during the intercalation reaction in lithium battery. In many weekly regular meetings with Greg, Yatish, Teng, Yan and Mu, I enjoyed this work during the designing, fabrication of rigs, Labview coding and debugging. I have presented my works in the BIAM-Imperial workshop twice.

After this one-year visit at Imperial, besides the improvement of my English, I have known even more about the fundamental issues about lithium battery, and tried to fill the gap between the basic science and industrial requirement. I hope this centre would be a good collaboration platform between BIAM and Imperial, and more academic visitors from BIAM and Imperial staff will involve in the upcoming project."

Dr Xiaofeng Zhang, Academic visitor since July 2015 – Characterisation and Degradation of All Solid-State Thin Film Lithium Battery – Dr Gregory Offer

“It is an honour for me to work in Imperial College London for six months as an academic visitor. It is really good experience to stay at Imperial to experience a different working environment. I enjoyed every moment and benefited a lot from here. I have learned some fundamental knowledge, characterisation skill and deformation modelling in powder metallurgy superalloy. More importantly, my English level and presentation skills have been improved. These are very useful for my research work in the near future. My supervisor, Dr Minh-son Pham, spent a lot of time and energy in the group discussion and TEM experiments for my programme. Thanks to Dr Pham and many people from BIAM center for all the help. It is much appreciated that the BIAM Centre has provided such a great chance for me to work here.”

Mr Jie Zhou, PhD student since October 2013 – Bird Strike – Dr Maria Charalambides & Prof John Dear

“I have been studying in the BIAM Centre for Materials Characterisation, Processing and Modelling for the past three years, and I have benefited a lot from the Centre which has offered me many opportunities to apply my academic knowledge in the industrial applications. Through collaborations with the visiting researchers from BIAM, I have gained a great deal of practical knowledge of powder forging technique, especially the status of powders during the whole forging process. This helped me a lot to establish and modify the theoretical bonding model for powder forging in my research work. Furthermore, the BIAM centre has provided me with the graphite tools for Gleeble powder forging tests, and supported me to conduct the tensile test for miniature components. I am so grateful for this experience to work in the centre to pursue my PhD.”

Dr Wenyong Xu, academic visitor from March 2016 – Microstructure Analysis and Creep Behaviour Modelling of Powder Metallurgy Superalloy – Dr Minh-Son Pham

“BIAM has sponsored my PhD project in the past three years, during which I have investigated the experimental and numerical characterisation of soft impact loading on aircraft materials, i.e. aircraft transparencies. Thanks to the great supports from BIAM, we have been able to use the gas gun facility to study the material behaviours under the high-velocity impact loading, such as the bird strike; additionally, the BIAM academic visitors played a key role in my project, from the technical advice to the project collaboration, in which I learnt the industrial way of dealing with engineering projects and how to maximise the personal contribution in the teamwork. During the past three years, we managed to publish three journal papers and six conference papers, which were embedded by huge efforts from each member in this team. At last, I would like to express my sincere gratitude to BIAM and Imperial College for offering me this research opportunity, more importantly, this process has built a bridge between the East and West, from which I have been participating in both sides.”

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Mr Yi Wang (2), PhD student since October 2013 – Modelling of Diffusion Bonding in Powder Forging – Dr Daniel Balint & Professor Jianguo Lin
Development of chemically toughened glass allows designing lightweight and strong transparent structures. In this project, a new 3D DIC monitoring method has been developed to calculate flexural bending stress and to make the study of laminated glass’s structural performance in better chance at quasi-static level. The following progress has been achieved:

• 3D DIC strain measurement with coaxial ring on ring compression test is a valid measuring method and can be a test protocol to visualise the strain and displacement changes in a specimen’s supporting glass side.
• 3D DIC results of monolithic glasses show a transition from flexural nonlinear bending in 2.0 mm and 4.0 mm thickness to linear bending in 6.0 mm thickness. The calculated flexural bending strength is presented by a two parameter Weibull distribution.
• Laminated glass using SGP shows catastrophic fracture similar to glass of equivalent thickness whereby the interlayer could not hold much fragments after the test.
• Based on the results of both ring loading and rubber loading tests, in terms of energy absorption, the 2.2 mm loading glass side with chemically strengthened conditions shows better performance than that strengthened thermally.
• Multi-layered interlayering has not demonstrated significant improvement of structural performance in either the quasi-static ring or rubber loading tests.
• Under the same geometric conditions, laminated glass using TPU showed better structural performance than the lamination using PVB.
• The strain level needed to break both the monolithic glass plate and the supporting glass side from laminated glass are all around 0.8 % for chemically strengthened glasses.
• In comparisons of ring loading methods, rubber loading can provide a higher peak load before the second fracture if the 2.2 mm glass ply breaks first.

Bird strike poses a major threat to key aircraft components, such as the windshield, and leads to massive financial losses each year. Numerous experimental tests for bird strike have been carried out, but due to the high cost and time consumption involved in the test, reliable analysis simulation tools need to be developed to evaluate the structural response of the “bird” and target. The aim of the project is to numerically simulate the bird strike process to improve the safety design of windshield in the pilot culprit. For the current investigation, the following conclusions are drawn:

• In the compliant target investigation, an additional space is created between the pin and the aluminium material when the impactor hits the target and the whole target start to be dragged towards the middle.
• The actual central back displacement is expected to be larger when considering the extra space being made.
• A comparison between the simulation results by Hedayati and the current ones was made and used as a verification for the developed model.
• The back displacement and strain were measured using the 3D DIC and strain gauge was used as a verification tool for the DIC results.
• All four sets of data from laminated glass test using gelatine as the projectile show a close match-up between the DIC and strain gauge data, which assures the data accuracy of the DIC test.
• SPH and Eulerian FE approaches have been applied to simulate the process. SPH shows more similarities than Eulerian in terms of the maximum back displacement.

Start: October 2012
Expected end: September 2016

Start: October 2013
Expected end: September 2016

Research Associate: Dr Iman Mohagheghian; PhD: Yi Wang; Visiting Academics: Dr Xintao Guo, Dr Xiaowen Zhang, Dr Liangbao Jiang

Research Associate: Dr Iman Mohagheghian; PhD: Jie Zhou
For battery related technologies, currently many systems are used outside of normally studied conditions which at best result in poor performance or over-engineered solutions, and at worst failure. This project aims to develop operational models that include degradation & failure that are capable of performing at extremes of operation, both very high charge/discharge rates and low and high temperatures. The progress that has been achieved includes:

- The cell has been tested at temperature up to 100 °C with and without compression applied. The compression reduces capacity and power fade of the cell after high-temperature testing.
- The compression also eliminates the capacity recovery process which means cell could be used to its full capacity sooner after a high-temperature excursion.
- Electrolyte evaporation is identified as the mechanism that could be suppressed by applying compression.
- Modelling work of Li-ion battery degradation has been initiated.
- The temperature inhomogeneity will cause substantial deviation from the nominal discharge rate, therefore accelerate degradation further.

Nickel base superalloys are extensively used in elevated temperature environment such as aerospace industry for aircraft jet engines application due to their excellent strength, ductility, fatigue resistance and oxidation resistance at high temperature. The primary objectives of this work are: 1. to analyse y' size distribution and morphology change corresponding to different heat treatments applied to FGH96 samples as well as the y' volume fraction and particle number density via SEM and 3DAP; 2. to understand the compositional difference between different generations of y' and the relationships with cooling rate as well as the near-field and far-field y phase compositions carried out by 3DAP analysis. 3. to identify y/ y' interface width for both secondary and tertiary precipitates from different heat treatments based on the proxigrams obtained from 3DAP experiment; 4. to develop a model illustrating the mechanism for y' nucleation and growth and the elemental diffusion behaviour upon cooling for a better understanding. The progress of the study is listed as follows:

- With increasing cooling rate both secondary and tertiary y' average sizes decrease.
- Higher cooling rate leads to a narrower secondary y' distribution and the size corresponding to peak frequency moves toward a smaller value.
- 3DAP analysis shows average tertiary y' sizes are different from SEM analysis but still decreases with increasing cooling rate.
- y' free depletion zones are found adjacent to secondary y' precipitates in y matrix.
- Tertiary y' precipitates are found to be smaller in size near depletion zones and bigger away from.
- Compositions of y and y' phase show that y' is enriched in Al, Ti, and Nb, while y phase is enriched in Cr, Co and Mo. Local y' compositional equilibriums are achieved at secondary y' centre with minimum impact from cooling rates.
- Tungsten concentration peaks are found at y/ y' interface, which is believed to be the evidence of W retarding coarsening at high temperature.
- Local y phase compositional variations prove that equilibrium is achieved close to y/y' interface but deviating from equilibrium when probing away from interface and the tendency of driving away from equilibrium increases with cooling rate.
- Interface width between y and y' measured from isosurface proxigrams show that it increases with cooling rate and this value is greater for tertiary than secondary.

**PhD: Yan Zhao; Visiting Academics: Dr Xiaofeng Zhang, Dr. Mu Chen**

**Start: October 2013**
**Expected end: September 2017**

**Research Projects**

**Characterisation and Degradation of All Solid-State Thin Film Lithium Battery**

**Characterisation and Modelling of the Mechanical Properties of the Isolated Phases in y/y' Microstructure**
Research Projects

Investigating the Mechanical Stresses that Arise in a Functionally Graded Engineering Superalloy

This project aims to use μ-mechanical testing to understand the performance of bespoke jet engine components. This unique and novel technique, spearheaded by authors such as Dimiduk and Uchich can provide high fidelity mechanical data that can be used in tandem with micromechanical models to quantify the performance of individual microstructural units for many types of in service behaviour. The followings list the progress that has been made:

• The carbides in CMSX-4 are needle shaped and coincide with TCP phases formed during the pack aluminisation process which occurs at ~700-800°C. These phases were found to inhibit the strength of the pillars.
• TCP phases are generally found to be brittle and have low ductility / cause loss of mechanical properties.
• Some studies show that small amounts of TCP formation can be beneficial to creep rupture strength.
• The carbides in CMSX-10 act to increase the strength of the alloy, this could be due to the large solution treatment window of CMSX-10 which allows more stable precipitates to form.
• TEM analysis can be performed to determine crystal orientations and degrees of misfit.

Start: June 2014
Expected end: May 2017

PhD: Suki Adande

Development of a Direct Powder Forging Process

Nickel-based superalloys have been widely used as high temperature structural material for a range of applications, and hot isostatic pressing (HIPing) is the most common method for manufacturing nickel-based superalloy parts. The aim of this project is to develop a direct powder forging process to meet the requirements of rapid manufacturing of FGH96 superalloy parts. The following progress has been made:

• The constitutive model of FGH96 nickel-based superalloy powder has been modified by introducing the powder density evolution.
• Powder density evolution has been calculated to further investigate the effects of process parameters.
• Small-scale powder forging experiment has been conducted to investigate the effects of process parameters on mechanical properties of components manufactured by direct powder forging process.
• Tensile test results of small-scale powder forging experiment samples have been obtained.
• Developed a theoretical diffusion bonding model (mechanism-based) for powder forging and a micromechanical model (RVE model) to simulate the powder compaction process.
• Combined the theoretical model with the micromechanical model to predict the bonding status between powder particles.
• Demonstrated the functions of the bonding model using a hemisphere model.

Start: March 2013
Expected end: September 2016

Research Associate: Dr Qian Bai; PhD: Jiaying Jiang, Yi Wang (2); Visiting Academics: Dr Xiaoming Zhou, Prof Shuyun Wang, Dr Yunpeng Dong; Dr Shuang Fang, Dr Qiuying Yu, Dr Yanju Wang
Research Projects

Optimisation of forming condition of TiAl alloy and simulations to its fatigue behaviour via CPFE

Gamma TiAl intermetallic alloys are innovative high temperature structural materials which have exceptional high temperature mechanical properties, but only have half density of nickel-based superalloys. Replacing nickel-based superalloys in aero-engines with these lightweight gamma TiAl alloys can achieve 20% increase in fuel efficiency as well as ~30% reduction in CO2. However, forming these TiAl alloys is extremely difficult due to the low ductility caused by their internal strong intermetallic bonds. This forming challenge results in high processing cost which is over 20 times more expensive than conventional Ti or nickel alloys. Thus, one of the aims of this project is to understand the deformation mechanisms of gamma TiAl alloys with the hope to develop a novel and cost effective forming method. During deformation, internal stress will be generated due to the strong anisotropic properties in both elasticity and plasticity for constitutive phases, which in turn influence significantly the mechanical properties of TiAl alloys. Therefore, it is necessary to reveal their microscopic processes during tensile and fatigue condition, including the generation and evolution of dislocation and internal stress. Combining with experimental observations, it is expected to reveal the relationship between microstructures and mechanical properties.

- Macroscopic mechanical tests have been conducted to study the behaviour of these materials at various temperatures and strain rates.
- The stress and strain of these macroscopic tests have been used to determine an appropriate set of constitutive equations by using Matlab based Genetic Evolution Optimisation scheme.
- Electron back scatter diffraction (EBSD) and high resolution EBSD will be carried out to reveal microstructure and dislocation density evolution which will provide more insights into the deformation mechanisms including recrystallisation process.
- Simulations are being conducted focusing especially on lamellar microstructure by using crystal plasticity finite element (CPFE) methods.
- The dislocation slip rules for main constitutive phases of TiAl alloy have been developed and calibrated according to experimental reports.
- The preliminary modelling results show highly anisotropic deformation and generation of internal stresses during tensile deformation, which is consistent with previous literatures.

![Cast gamma TiAl microstructure](image1)

![Forged gamma TiAl microstructure](image2)

![Contour map of plastic strain showing anisotropic deformation history](image3)

Equipment

An extensive range of equipment is available to the researchers within the Centre.

Heavy Testing Machines

A 250 Tonne hydraulic forming press and 100 Tonne high-speed (up to 1.6 m/s) hydraulic forming press are available. These machines can act in tension and compression and can be used for three-point bending tests and forging tests. The 100 Tonne high-speed press can also be used for large scale fatigue tests. The machines can be fitted with furnace heaters that allow controlled high temperature testing (up to 1200 °C).

High-rate Testing Machines

There are 25 Tonne (up to 5 m/s) and 2 Tonne (up to 25 m/s) testing machines available for high strain rate tests. These machines are important for studying strain-rate dependent effects such as work hardening and can be used for impact research.
Equipment

Gleeble Thermo-Mechanical Simulator
The Gleeble 3800 is a fully integrated digital closed loop thermal and mechanical testing system. Specimens can be heated at rates up to a maximum 10,000 °C/s by resistance heating, or can be held at constant temperature. It is capable of exerting up to 20 tonnes of static force in compression or 10 tonnes in tension, with applied displacement rates up to 2 m/s. Feedback consists of linear variable differential transformers, load cells or non-contact laser extensometry.

Optical Strain Mapping
The optical techniques available within the Centre include Digital Image Correlation (including Speckle and Grid Patterning), Electronic Speckle Pattern Interferometry and Moiré Interferometry. Digital Image Correlation provides 3D deformation mapping.

X-ray Diffraction
A wide range of X-ray diffraction techniques are available within Imperial College for the investigation of polycrystalline materials, single crystal and thin films. Samples may be examined in either bulk or powdered form. There are currently 2 PANalytical MRDs, 2 PANalytical MPDs and a Bruker D2 desk-top instrument for rapid data collection. There is also a high temperature X-ray diffraction facility. X-ray diffraction measurements can be performed at elevated temperatures up to 1000 °C using a combination of direct and indirect heating. This allows the investigation of the thermal behaviour of lattice parameters, crystallisation studies, and the detection and characterisation of high temperature phases. The high temperature chamber is fitted with a system to allow measurements to be made in controlled atmospheres (including oxidative) so that structural changes related to sample-gas interactions can be studied.

Neutron Diffraction
Imperial have been greatly successful in being awarded beam time at a number of research institutes including ISIS, UK; Helmholtz-Zentrum, Berlin; Institut Laue-Langevin, France; Heinz Maier-Leibnitz, Munich and The Paul Scherrer Institute, Switzerland. The highly penetrative neutron diffraction technique is well established for measuring 3D residual stresses deep within in a volume of material, non-destructively. Imperial have widely employed the technique to measure macro scale residual stresses and strains, typically in welded non-uniformly plastic deformed components. These measurements have been valuable for the verification of finite element models to simulate the welding or deformation process and predict the residual stress fields. The method has also been employed to measure intergranular strains in alloys and used to develop and verify crystal plasticity models.

Gas Gun
A new gas gun has been installed in the lab. The gas gun has a fast launching mechanism allowing firing ice balls as well as rubber and gelatine projectiles. The gas gun can be connected to both compressed air and helium to the pressure up to 10 bar. The target area is designed with polycarbonate windows allowing the strain mapping of the sample under impact. The gun has 3 m long barrels in three different diameters including 10, 25 and 40 mm.

Materials Characterisation
The Harvey Flower Microstructural Characterisation Centre in the Department of Materials for electron microscopy provides modern facilities for advanced materials imaging and characterisation. The facilities include three scanning electron microscopes (SEMs) and three transmission electron microscopes (TEMs). This includes the state-of-the-art monochromated FEI TITAN 80/300 and FEI Helios NanoLab 600 DualBeam TEM. In addition, a dedicated microscopy team maintains the latest technology in the two sample preparation labs and data processing suite.

Metal Additive Manufacturing Suite
Concept-laser Mlab cusing R and Renishaw AM250 (30μm & 70μm)
The AM25 has a build rate of 5 cm³ - 20 cm³ per hour over an area of 250 x 250 up to 360mm high, the addition of 70 μm diameter powders can create complex shapes in stainless steel, inconel, titanium and aluminium. The Mlab cusing R has a build envelope of 90 x 90 x 80 mm with 35μm

Polymer Additive Manufacturing
The da Vinci 1.0 by XYZprinting has a printing envelope of 200x200x200mm with a layer resolution of up to 200 μm and a filament diameter of 0.4 mm.

Multi-Point Forming Tooling
A modular flexible tool for the creep-age forming of extra-large panel components has been designed, built and patented. An integrated optimisation process for tool offsetting is demonstrated in published results. The method can be used to make flexible CAF tools with less than 1 mm error in the forming surface. In addition, this error can eventually be compensated and thus eliminated from the CA-formed parts, by using the developed optimisation technique.
Events

A number of events have taken place to facilitate research interaction and deep dialogue regarding the Centre’s work and direction.

BIAM Centre Workshop in Beijing

24 May 2016

BIAM: Professor Shenglong Dai, Professor Yajun Wang, Professor Xingwu Li, Professor Feng Lu, Mr Zhiguo Zhang, Dr Kun Zhang, Professor Yue Yan, Professor Jinwen Zou, Professor Yiwei Shi, Dr Yongjun Guan, Professor Shuyun Wang, Mr Xiaochang Xie, Ms Tian Tian

Imperial: Professor Jianguo Lin, Professor John Dear, Professor Fionn Dunne, Mr. Nik Pishavadia, Dr Liliang Wang, Dr Jun Jiang, Dr Zhusheng Shi, Dr Dimitris Sarantaridis

BIAM Centre Workshop in London

4 July 2016

BIAM: Professor Yajun Wang, Professor Feng Lu, Professor Jinwen Zou, Professor Yiwei Shi, Professor Yue Yan, Professor Xiaohong Wang, Professor Xiaoguang Liu, Ms Tian Tian

Imperial: Professor Jianguo Lin, Professor John Dear, Professor Fionn Dunne, Dr Xiaooy Xi, Dr Catrin Davies, Dr Gregory Offer, Dr Ben Britton, Dr Minh-Son Pham, Dr Liliang Wang, Dr Zhusheng Shi, Dr Jun Jiang, Dr Iman Mohagheghian
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