Institution: University of Birmingham

Unit of Assessment: Metallurgy and Materials (UOA 13b)

a. Overview

Our underlying driver for long term success is for each individual member of staff to strive to attain international recognition for his or her research, and our aim is to provide the best academic environment to further such ambitions. All eligible staff (formerly category 'A' staff) have been submitted for this exercise and we have six early career researchers (each of whom has submitted four papers for RA2). The School allows all individuals freedom to pursue their own research ideas, often facilitated by the provision of research students. Research groups are designed to ensure that major research equipment and facilities are accessible, maintained and developed further. With a replacement value now estimated at over £40M, these facilities and equipment are used by large numbers of doctoral and postdoctoral researchers (115 and 50 respectively as on 31st October 2013), and so research groups are essential to provide resource balanced across the School. These four groups are:

(i) Alloy Processing and Process Simulation. (Research Group A)

Leadership is from two Professors (**Brooks, Dong**) five senior staff (**Adkins, Basoalto, Chang, Griffiths, Ward**) and a younger member of staff (**Attallah**). These eight academics are supported by thirty-three doctoral researchers, twenty-six postdoctoral researchers, two senior research technical staff and eight research technical staff.

(ii) Functional Materials. **(Research Group B)**

Leadership from two Professors (**Button, Fernando**), five senior staff (**Book, Crisan, Kukureka, Jenkins, Stamboulis**) and two younger members of staff (**Laver, Walton**). These nine members of academic staff are supported by twenty-one doctoral researchers, nine postdoctoral researchers, two senior research technical staff and five research technical staff.

(iii) Materials Characterisation, Alloy Development and Materials Modelling. (Research Group C)

Leadership from one Professor (**Jones**), two senior staff (**Hu, Strangwood**) and with several younger members of staff (**Chiu, Mottura, Warnken**). These six members of staff are supported by twenty doctoral researchers, three postdoctoral researchers, one senior research technical staff and three research technical staff.

(iv) Engineering Properties and Degradation. (Research Group D)

Leadership from three Professors (**Bowen, Davis, Evans**) three senior staff (**Connolly, Davenport**, **Ponton**) and a younger member of staff (**Papaelias**). These seven academics are supported by forty-one doctoral researchers, twelve postdoctoral researchers, one senior research technical staff and two research technical staff.

b. Research strategy

Vision and Strategic Plans

The School vision is to carry out research of international quality in areas which provide fundamental underpinning for improvement of the industrial/technological base for the UK. The strategy employed by the School to achieve its research aims is to maintain a broad, state-of-the-art infrastructure of research facilities and support (technical staff and students), which can be drawn upon by individuals or groups to address new areas of interest. The School's research effort is distributed between our four groups working on core programmes in the processing, characterisation and assessment of materials. Metallurgy is core to much of our research activity (with 77% of staff engaged on research into both ferrous and non-ferrous metals). These groups reflect the central thrusts of the research REF outputs from individual academics although there is considerable overlap of interests (see REF2 papers). Groups are represented by their professors on the School Research Committee which initiates and pursues strategies for the updating and expansion of key facilities. It also advises the Head of School on resource issues such as space and technical support. All groups are linked strongly with industry. Typically one hundred companies are engaged with our research programmes each year. This industrial involvement is essential to our research ethos, and we target aerospace and nuclear power sectors in particular. Our strategy includes large-scale processing activities and we have a natural focus currently, and increasingly so for the future, on 'High Value Manufacturing'. In order to progress our strategy it is essential that we secure nationally competitive research awards both at individual and School levels. Total research income over the period is £31.5M, and income per FTE member of staff (noting all eligible staff (29.1 FTE) have been entered into REF) has thus averaged £1.08M.

Research awards have risen sharply (to over £9.4M) in 2012-2013 and the School can look forward to the future with confidence. We also make use of Large Facilities within the UK (where this resource is valued at £1M over this assessment period) and those overseas (Diamond Light Source, ISIS, SLS, APS and ESRF). Our aim is to maintain and, if possible, improve upon the excellence of the research in the School and to ensure that our efforts are focused into areas that are timely and of relevance to wealth creation. Indeed the detailed research that underpins so many of our technology-related achievements relies on thorough microstructural characterisation and understanding of mechanisms using state-of-the-art equipment and techniques.

The vitality of the research strategy within the School also relies considerably on the excellence of our doctoral researchers. On 31st October 2013, 115 PhD/EngD doctoral researchers were in full-time registration on three/four year research programmes, together with 26 MRes students on a one year research programme. They create resource of £3.2M per annum (including fees) and allow much speculative research to be undertaken. It is School strategy to provide partial scholarship support to several prestigious and competitive schemes for overseas students (including CSC and Roberto Rocca awards for Chinese and South American candidates respectively). These students are often supported to carry out research into areas of strategic importance to the School (such as electron microscopy), but for which industrial support may be difficult to obtain. Note that to date the School strategy has been not to pursue postgraduate taught MSc programmes. Aspects of our strategic plan are best illustrated by the following examples of areas that we have targeted, where we have been successful over this current period and which we will develop further over the next five years.

i) Our Strategic Partnership with Rolls-Royce.

Rolls-Royce remains our most critical industrial collaboration, (with 63% of staff having some involvement in such programmes) and we have now established the University of Birmingham as one of the largest HEI partners to Rolls-Royce globally. Interactions with Rolls-Royce are extensive, are centered on our School of Metallurgy and Materials and are essential in keeping Rolls-Royce's materials research anchored in the UK in the face of global alternatives. One essential aim for 2014 is to renew the £50M Rolls-Royce/EPSRC Strategic Partnership (established in 2009), in line with its ten year memorandum of understanding. The Birmingham elements of this integrated training and research partnership are critical to the ongoing health of our core metallurgical research into structural metals. Upon renewal, it is likely that support to Birmingham will continue to address the full spectrum of our current metallurgical activities.

ii) The Manufacturing Technology Centre (MTC), Ansty.

A significant achievement for the School over this period of assessment is the establishment of MTC. This £40M AWM/EMDA regional development agency initiative (now supported by £10M Catapult funding annually) was initiated by the School (under the title of ROTOFRIC, originally a £8M programme with Rolls-Royce and TWI) to develop the use of rotary friction (inertia) welding. Birmingham's involvement originated from a deep understanding of microstructure -property-behaviour relationships especially with reference to defect tolerance and crack growth in such welds. This project caught the imagination of senior executives at Rolls-Royce, was developed further and has resulted in a 12,000 m^2 facility, owned by three Universities (Birmingham, Nottingham and Loughborough) and TWI, and launched in late 2010. The School provides metallurgical expertise in support of major manufacturing projects (MCRL/TRL 4-6), with Mechanical/Manufacturing expertise provided to date by Nottingham and Loughborough Universities. These interactions provide excellent opportunities to develop further large-scale research programmes in the near future. The School features prominently in two MTC themes: High Integrity Welding and Fabrication and Net Shape Manufacturing; and is in full partnership on a third theme on Process Modelling and Simulation through the joint ERDF programme CASiM^2, launched in September 2012 (between Rolls-Royce, MTC and the School). For the next five years it is anticipated that the School will: strongly develop new joint EU framework programmes in Net Shape Manufacturing (with complementary expertise on electron beam melting at MTC and laser powder processing and melting at Birmingham); exploit expertise in the characterisation and assessment of friction welded components to secure large TSB/BIS/Catapult funding jointly with MTC; and establish a major UK effort in Process Modelling and Simulation again in collaboration with MTC. These joint programmes are expected to fund a minimum of fifteen postdoctoral researchers and twenty doctoral researchers in steady-state at Birmingham in addition to existing researchers in post today.

iii) The High Temperature Research Centre (HTRC), Ansty

A further significant achievement for the School over this period of assessment was winning this HEFCE £20M sponsored capital programme (building and IT infrastructure) in strict competition in 2012. It has guaranteed £40M of research sponsorship in capital equipment (£19M) and revenue streams (£21M) from Rolls-Royce, in the area of investment casting. The School's track record in large-scale processing combined with its mature relationship with Rolls-Royce proved crucial in assembling the bid. Funding streams from many sources (EPSRC, RAE, TSB, BIS) are expected to provide opportunities for HTRC, not least for the immediate recruitment of a Research Chair in Investment Casting and Director of HTRC (University position). Its location in close proximity to MTC marks the advent of major activity remote from the School. An increase in casting research by some forty doctoral and postdoctoral researchers is a target for 2016 (the building will open in March 2015). The future strategy for the Centre will be directed in combination with the School of Chemical Engineering (who will concentrate on research into refractories). Initially it will impact directly on the competitiveness of Rolls-Royce within its core turbine blade technologies and components. Specifically, over the next five years it will deliver: step-changes in 'fast design and make capability' through process modelling (ultimately at a systems level); underpinning casting materials research (development of new alloys and their castability); and radical process improvements and predictive process modelling (validated through full instrumentation of production scale facilities). In the longer term it will stimulate research into ICT tools to enhance product quality and efficiency (in collaboration with the School of Mechanical Engineering). Once established fully, HTRC is expected to stimulate research into casting technologies across wider transportation and medical sectors.

iv) Critical Materials

Over this assessment period the area of functional materials has received a significant boost by the recruitment of two new researchers (**Laver, Walton**), and with expanding activity in hydrogen storage and processing (**Book**) and sensors (**Fernando**). Niche areas relating to magnetic (especially rare-earth) materials and hydrogen storage and processing are progressing in a vibrant manner. Grants to a value of £1.2M have recently been secured, with a further ten major grant applications (EPSRC, TSB, EU) submitted under the general umbrella of functional materials. Discussions have been initiated to develop an initiative (with collaborators in Chemical Engineering and Chemistry) in the area of strategic chemical elements (both rare earth and platinum group metals) encompassing reclamation, recycling and replacement/reduction of these elements in a variety of applications, including magnetic and other functional devices, and high performance structural alloys. 'Critical Materials' will play a large part in Horizon 2020, where resource efficiency and raw materials are key themes in the document. Rare earth metals also feature prominently and thus new funding for permanent magnet research is additionally tied into these critical materials themes. There are a large number of projects in the US, Japan and the EU working on the efficient use of rare earth metals in magnets, investigation of new permanent magnetic materials and recycling of rare earth magnets. Thus a crucial part of our vitality in functional materials for the next five year period relies on our ability to exploit these areas where we can claim both ownership and expertise which is recognised world-wide.

v) European initiatives in 'large-scale' metallurgy

Currently within Europe there are major initiatives planned around large-scale metallurgical programmes (both in size and scope) and in particular the idea that 'High Value Manufacturing' ambitions are underpinned by detailed scientific understanding of microstructural control and prediction of behaviour. Birmingham is ideally placed to collaborate fully in such programmes, from process modelling and simulation of behaviour, to materials characterisation, validation of models and behaviour in service through experimental investigations at the appropriate scale. Location-specific process and materials modelling remain significant directions of research for the US, and they feature strongly in the ambitions of our materials, modelling and simulation group (**Basoalto, Brooks**).It will thus be our intention to exploit the full range of our research capabilities as such opportunities arise.

vi) Partnerships within the nuclear power sector

We have strong long-term collaborations with EDF Energy, Rolls-Royce, Nuclear Decommissioning Authority and Office of Nuclear Regulation. They involve seven academics and we will continue to prosecute research in specialised areas through which we contribute to national expertise and scientific capability. Here we are benefiting from a University initiative to develop a

Centre for Nuclear Education and Research. In conjunction with our Schools of Chemical Engineering and Physics, this initiative has established unique facilities for the characterisation of; the effect of material chemistry on corrosion and deposition within high purity light water reactor systems; and, materials properties and degradation as a function of light ion irradiation damage (within our cyclotron facility). We also see expansion in our support of the sustained operation of Advanced Gas-cooled Reactors, AGRs. These nuclear reactors presently provide some 15% of UK electricity generation and are an essential national asset particularly over the next ten-year period. We envisage providing the underlying science to help define solutions to materials problems associated with the long-term exposure to the reactor environment and to provide additional technical strength to safety cases. In the current and near term, one focus will be on assisting EDF Energy's efforts to ameliorate heat transfer impairment arising from carbon deposition on stainless steel fuel cladding surfaces, while ensuring that the graphite core remains robust to challenges to its structural integrity. These latter challenges arise from increased amounts of graphite brick cracking and increasing graphite weight loss.

Progress against the research plans described in RAE 2008

In our 2008 submission we looked forward to substantial research investment into all our areas of strength, notably: alloy processing, (including laser processing and manufacturing, and near net shape HIPing), engineering property assessment, characterisation and modelling and functional materials processing (where hydrogen storage and recycling of permanent magnet materials were highlighted). Our aspirations have been fulfilled and one unique feature of our School is to prosecute leading-edge research at a size-scale relevant to in-service components. As predicted, the development of improved alloys and their effective exploitation have been the primary focus of much of our research in this assessment period. This has ranged from fundamental alloy design and materials modelling (e.g. **Hu, Mottura, Reed** (2008-2012), **Warnken**), process simulation and validation (e.g. **Basoalto, Brooks, Reed** (2008-2012), processing (e.g. **Attallah, Green** (2008-2011), **Ward, Wu** (2008-2010)) and assessment (e.g. **Bowen, Connolly, Davis, Evans**) through to knowledge transfer and establishing independent research centres (MTC). Indeed, the MTC has already grown to employ 220 individuals and has 60 industrial member companies.

In 2008, we also had ambitions to develop our large-scale plasma-melting facilities further and to procure large-scale inertia welding capability. Here we have taken a different route to access such large-facilities. In the first case, we have formed a long-term partnership (2012) with TIMET (of an initial value of £1M) as a result of which we have transferred the furnace to a local site at Witton, Birmingham. It is now the focal point of a new multi-million pound research and development centre. TIMET have also invested in the furnace ($3M) to uprate it and to allow commercial production of titanium aluminide alloys in the UK. We retain appropriate access to the facility for academic research into plasma melting and we provide technical expertise to support this exciting development on an ongoing basis (and in particular with respect to the development of titanium aluminides). In the second case, the development of inertia welding capability at MTC provides the perfect opportunity for collaborative research at the necessary size-scale.

All our major research areas continue to thrive and we have received significant recent investment in: infrastructure (the £37M refurbishment of Metallurgy and Materials completed in mid-2013); and capital equipment for simulation and processing (£0.8M, CASiM), and microstructural characterisation (£1.9M, CHART) during 2013. Predicted capital expenditure for HTRC amounts to £19M (in collaboration with Rolls-Royce), and these facilities will stimulate further our long-term interdisciplinary research with both Chemical Engineering and Mechanical Engineering at Birmingham.

c. People, including:

i. Staffing strategy and staff development

Staff Profile.

During the assessment period, there have been significant (sixteen) changes in (formerly category 'A') staff submitted (including seven ECRs), the FTE number has risen to 29.1 (a headcount of 30) and the average age is 47 years. Staff include eight Professors, two Readers, five Senior Research Fellows, seven Senior Lecturers, three Birmingham Fellows (open-term) and four Lecturers. The numbers of postdoctoral research fellows, postgraduate research students (including MRes students) and research technical staff at the census date are 50,141 and 24 respectively. New open-term appointments are: **Brooks** to a Chair**; Basoalto, Laver** to University

Senior Research Fellowships; **Mottura**, **Papaelias** to University Research Fellowships and **Attallah, Chiu, Warnken** to Lectureships.

Staff changes since the last RAE (2008) are **Abell, Harris and Knott** into full retirement and **Jones** into partial retirement. The retention of Jones will ensure continuity during the next transition period. Other staff changes are: **Bell** (deceased), **Williams** (deceased), **Green** (to Doncasters, UK), **Reed** (to Oxford University) and **Wu** (to Monash University, Australia). Senior staff now in retirement – **Abel**, **Harris**, **Knott**, **Loretto** and **Smallman** still have office space in the School and can be readily accessed by students and research fellows alike, to give advice and share experience.

Staffing strategy and development.

Our research groups link to major facilities, support critical themes and control significant resource (doctoral researchers, postdoctoral researchers, research technical staff) within the School. These core research themes are embedded deeply, are broadly based and have proved to be robust to changes in funding priorities. Our staffing strategy is therefore centred on maintaining and developing these research themes. Over the current assessment period we have been successful in strengthening all of our four research groups, through eight new appointments, in terms of: theoretical capabilities in materials characterisation, alloy development and materials modelling (**Chiu, Mottura, Warnken**); alloy processing and process simulation (**Basoalto, Brooks**); non-destructive testing and condition monitoring (**Papaelias**); and functional materials (**Laver, Walton**). Naturally we also respond in a timely fashion to replace key senior staff who leave (for example, **Reed**, by **Basoalto**, **Brooks**), although often we give an opportunity for more junior staff working within the area to expand their research first (**Attallah** after the loss of **Wu**) and prior to any re-appointment at a senior level. In all cases, any appointment is based primarily on the quality of the candidate and our broadly based research themes facilitate this recruitment strategy. Promotions (all fully externally refereed) are: **Davis**, **Dong** to Personal Chairs; **Book** to Reader; **Connolly, Griffiths** to Senior Lecturers. Over the next period of five years we have at least five individuals who are expected to be strong contenders for promotion to Personal Chairs.

Of staff submitted to this REF, 53% originate from fourteen individual countries outside the UK: Australia, USA (2), China, Hong Kong, Chile, South Africa, Peru, Sri Lanka, Greece, Romania, Italy, Egypt, Eire and Germany. In addition these staff have been recruited to the School while working in a variety of countries including USA, Switzerland and New Zealand. This reflects our desire to recruit widely to secure the best possible academics for our positions. The University has a strong commitment to equality and diversity, as evidenced through its Equality Scheme and membership of organisations such as the Athena SWAN Charter (Bronze membership) and Stonewall. Within the School three of our staff submitted to this REF are female – all occupy senior positions within the School, and two have combined their careers to date with periods of maternity leave. During such periods of maternity leave, all supervision of postgraduate research students is carried out by co-supervisors (all students have at least two supervisors), thus ensuring continuity in the student's research, and on return flexible working practices are available. We have an example involving working from home for two days a week for an extended period, with a small reduction in FTE to meet family commitments. Whenever possible (and we have two examples within the current period of assessment) it is also School policy to provide full scholarship support to postgraduate students on maternity leave.

Arrangements for developing and supporting staff.

All staff are supported in their research by ensuring that there is ready access to postgraduate researchers and technician and computing support (24 FTEs). Administration and teaching loads allow many staff to devote 50% of their total time to research activities. Thus, it is possible for established members of staff to continue to re-assess their research activities and to change the direction of their research as necessary in the light of both new scientific opportunities and challenges in the funding landscape.

Developing the research of colleagues new to research.

New members of staff on first appointment are assigned to a mentor, are supported for international travel, have preferential access to fully-funded studentships (within our various industrial partnerships and particularly from our DTG awards) and are given advice on EPSRC first grant applications. During probation they work closely with more senior members of staff (e.g. **Warnken** with **Reed** (now **Brooks**), **Mottura** with **Jones**, **Laver** with **Dong**, **Attallah** and **Papaelias** with **Davis**). Other teaching and administrative duties are minimised during this period.

This often allows a research group to be built rapidly: e.g. **Attallah, Mottura, Papaelias, Warnken** currently act as principal supervisors for 23 doctoral researchers and 11 postdoctoral researchers.

Early career researchers are thus afforded many opportunities for rapid progression (noting that they are often appointed to areas of strategic importance to the School (e.g. **Warnken, Mottura, Laver**), and/or they have established already a strong research presence (e.g. **Papaelias, Walton**) and are closely mentored during any probation period). All staff are supported in terms of the recruitment of research students, conference activities and the strong research ethos of the School allows researchers to flourish.

Sustainable staffing structures and strategic planning in the recruitment and retention of staff.

Our view is that research across the broad materials spectrum requires a minimum of 20 FTE permanent academic staff. All new positions at Birmingham have to be won competitively and must have a strategic fit. Both business cases and University endorsement are required. Retention has not been a significant issue and we take great care at the recruitment stage. Balance across our research groupings is important, although quality *per se* is our overriding consideration. It is essential that we take the opportunity afforded by the development of HTRC to recruit a world-leading Professor of Casting (to replace **Green**). Of equal importance, will be to identify a further senior academic to replace **Jones** to lead our characterisation efforts, on, or before, his eventual retirement (anticipated for late 2015). With these two additional senior appointments all research areas will have appropriate leadership over the next five years - allowing the situation to be reviewed further in 2016.

The School is acutely aware as to its responsibility for all postdoctoral researchers and it is pleased to conform to the Research Concordat. Thus they receive individual professional development reviews annually during their first three years of appointment. Moreover, they have a well-established career path within the School (and which follows from the opportunities established originally for the IRC, 1989-1999). We have thirteen postdoctoral researchers who have progressed to senior grades (eight and nine), two who have progressed to Readerships and one to a full Professorship. These experienced staff members provide specialist expertise across the broad spectrum of processing, characterisation, simulation and behaviour.

It is also important to acknowledge the vital contribution to our research activities that our experienced technical support staff team makes - especially in view of the large-scale experiments which are often a feature of our studies. It is thus critical to ensure that we maintain an appropriate number of such support staff so that we continue to attract large-scale industrial projects with proper regard for health and safety issues**.** The replacement of such talented and experienced research technical staff on their retirement is a priority for us. For example, we are considering how a series of 'staff scientist' positions could alleviate any such problem within the next five years and this strategy links to development opportunities for some postdoctoral researchers.

Developing research culture.

Overall strategic direction is provided by the School Research Committee with input from Research Group meetings, the College of EPS Research and KT Committee and the University Research strategy. Specific aspects which define and encourage the research culture of the School are: all staff are research active; doctoral researchers have a wide choice of research topic; there is an active programme of research colloquia (including those associated with the Birmingham Metallurgical Association, organised from within the School); students and new staff receive support to attend international conferences; sabbaticals are supported; good research infrastructure and international reputation attract foreign research visitors and students; regular Away Days on specific aspects of research.

The University's strong support of our School enables us to lead major new intra-University initiatives with Mechanical Engineering, Chemical Engineering, Computer Sciences and Physics. For example, the process modelling and simulation group (with a core capability of fifty modelling stations) under the leadership of **Brooks**, will broaden its activities to form a cross College research activity, involving many of the Schools within Engineering and Physical Sciences and linked closely to a similar group at MTC (and eventually HTRC). The newly refurbished ground floor laboratories within the School of Metallurgy and Materials will allow a new multi-disciplinary group to be formed around 'critical materials and their reclamation' led jointly by **Rowson** (Chemical Engineering) and **Walton**. This initiative will form the core of a large functional materials interdisciplinary activity which will integrate activities of powder processing, magnetic materials and rare-earth crystal growth.

ii. Research students

The recruitment of outstanding postgraduate research students has always been vital to the School. Typically of our target for entry of 50 per annum (including 20 MRes students), up to 30 will be international students (from outside the EU). Therefore our strategy requires us to win competitive awards for both home/EU students (including DTCs, IDTCs, Strategic Partnership, DTAs and iCASE) and international students (CSC and DHPA). Our competitive successes over the period of assessment, combined with generous industrial support, have enabled us to recruit thirty doctoral (PhD/EngD) students each year. Research excellence is the driving factor, with CSC scholarships typically four per annum. Over the period of this REF the School has also exploited the DHPA scheme (with Rolls-Royce) to support a total of 10 students. Home recruitment is through several DTCs, IDTCs, DTA and iCASE awards which allow fifteen students per annum to be recruited. These numbers of research students have allowed all members of staff opportunity to undertake long-term fundamental and often, speculative research.

We continue to educate large numbers of postgraduate research students (208) higher degrees (118 PhD/EngD and 90 MRes) awarded within this assessment period): a substantial proportion of these progress into British industry. Many of our postgraduate research students are on either EngD or MRes programmes with taught elements (4-6 intensive week-long taught modules per year) in both technical areas and professional "generic" areas such as communication, teambuilding and project management. PhD students may attend any technical modules. The teambuilding course (a residential course at the University's facility at Lake Coniston) is also available to PhD students. All research students are given training in the use of bibliographic software and literature searches. In addition to Health and Safety and Workshop Practice training, students are given individual training in the use of the extensive electron microscopy, physical characterisation and mechanical testing facilities, as required. Students have free access to microscopy, X-ray diffraction, AFM, DTA, fracture and fatigue testing, thermal analysis and corrosion testing. All students are members of the Graduate School, involving 7000 postgraduate students across the University. This encourages interactions amongst students of different disciplines and offers additional training in transferable skills. Progress monitoring of all students is undertaken formally at least once a year. Completion rates for doctoral students are above 90%, but sometimes their submissions are not within the period of normal registration. Before graduation, our students produce substantial numbers of papers and patents: fifteen students have won prizes for such publications over this assessment period. After graduation all secure appropriate employment – with typically 90% of students on collaborative programmes with industry offered employment by their sponsoring companies.

d. Income, infrastructure and facilities

Over the current assessment period there have been spectacular investments in major capital equipment and infrastructure by the University, ERDF, RDA (AWM), TIMET UK and Rolls Royce/EPSRC. In combination with previous investments, our research facilities are comprehensive, with capital investment in the areas of Alloy Processing and its Simulation (£16M), Functional Materials Processing (£6M), Characterisation and Alloy Development (£12M) and Engineering Properties and Degradation (£6M). In addition, as founding research partners of MTC, we have access to £18M of large-scale capital equipment located at Ansty Park, Coventry in areas of process simulation, high integrity joining, materials characterisation, non-destructive examination and net shape manufacturing (laser and electron beam deposition). On completion of HTRC, a further £19M of capital equipment will be used to prosecute world-leading interdisciplinary research (together with our School of Chemical Engineering) into the casting of single-crystal turbine blades in collaboration with Rolls-Royce. TIMET UK have invested in excess of $3M in updating our existing plasma arc melting facility and in our newly established research partnership (£1M) we will research into the plasma-melting of titanium aluminides over the next decade. These recent initiatives demonstrate our future strategy to continue to research into materials processing not only at a size-scale appropriate to simulate industrial practice at our main University site, (as we have carried out for several decades), but also to utilise external locations (TIMET UK at Witton, Birmingham and MTC, HTRC at Ansty Park, Coventry) to allow first-time introduction of our materials research into high value manufacturing for the benefit of UK plc.

Since 1966 the School has been housed in a building, initially awarded The Royal Institute of British Architects Bronze medal on opening and which has now become Grade II listed for its innovative ‘tartan grid’ design (Sir Philip Dowson). This magnificent example of “brutal” sixties

architecture combined with internal functionality has recently undergone a £37M investment (from the University and HEFCE) and re-opened fully in February 2013. The refurbishment has already won three architectural awards including a Certificate of Excellence in the Mature Structures Category from the Concrete Society and the Architects Journal Retrofit Award in the listed Building/Structures: Post war category. This investment underlines the University commitment to this School and provides an impressive base to prosecute world leading research. It is appropriate to acknowledge the strong support of the University in matching all our applications to enable substantial external grants to be leveraged through success in national competitions. New and uprated capital equipment secured during this assessment period includes major items in support of: characterisation – analytical transmission electron microscope, a FIB-FEGSEM, optical tomography, X-ray tomography and X-ray fluorescence to a value of £2.5M; processing – Concept laser system for direct laser fabrication and uprated Plasma Arc Melting (TIMET) to a value of £4.3M; and simulation studies/modelling facilities to a value of £1M (available through the joint CASiM2 programme).

Our research funding portfolio has remained stable throughout this current assessment period, with an average annual spend of £6.3M each year since 2008/2009 to give a total of £31.5M over this assessment period (excluding "in-kind" use of major facilities). This compares very favourably with that cited in the previous RAE 2008 exercise, of £23M (especially since this previous period of assessment was of a longer duration). Within the various funding streams, Industry and EU funding are becoming increasingly more important over time, relative to Research Council funding. This trend is likely to continue, but we will target major EPSRC grants in the near future (noting, for example, the likely initiatives in 'critical materials' where we are well placed to contribute markedly, and the renewal of the Rolls-Royce/EPSRC Strategic Partnership in 2014, where we play a pivotal role amongst several universities). The School has also been successful over this period in securing substantial UK (Regional Development Agency) Central Government Grants to develop its research infrastructure. Several members of staff continue to make use of UK (valued at £1M) and overseas Large Facilities and such involvement is part of our future strategy. Overall, our assessment is that we retain a sufficiently broad base (with 31, 32, 20 and 17% of our total £31.5M income in the current period deriving from Research Council, UK Central Government, UK Industry and EU Government (and Industry), respectively) to maintain a stable financial position through challenging times. If there continues to be an emphasis on 'High Value Manufacturing', together with renewed interest in the importance of metallurgical research to support such manufacturing, then we are confident that our research ethos and capabilities will allow us to play a prominent UK role. Certainly, we expect our postdoctoral researcher base to be maintained at fifty and that we shall engage significantly in additional research activity with MTC and HTRC.

Commercialisation of research within the School is supported overall by Alta Innovations Ltd, the University's technology transfer company, responsible for the protection of intellectual property, (including patent filing) and for arranging the most appropriate support mechanism for commercialisation. Alta also provides a route to access both public and private commercialisation funds. Currently academic staff hold a total of forty-six patents, with **Button** (seven), **Chang** (seven), **Crisan** (four), **Dong** (six), **Fernando** (ten), **Ponton** (four) contributing strongly.

Three spin-out companies continue: Metal Nanopowders Limited (**Chang** 2002), Applied Functional Materials Limited (**Button** 2004) and Ad.Surf.Eng.Ltd (**Dong** 2001). The first two of these have recently received EU FP7 funding of €412k and €382k respectively. In the ongoing development of these companies the School continues to provide key support in terms of accommodation, access to equipment and staff time.

e. Collaboration or contribution to the discipline or research base

National and international collaborations: all staff have good national and international connections. Of the 120 publications listed in RA2, 26 involve collaborators in other British universities, 41 involve collaborators from British industry and 44 involve collaborators abroad.

National and international scientific and professional bodies: over the current period of assessment staff have held twelve visiting scientist/professorial positions at overseas universities/research centres within Europe (France, **Stamboulis**, Spain, **Papaelias**, Germany, **Kukureka**, Czech Republic, **Button**, Romania, **Crisan**,) USA, **Kukureka**, **Laver, Mottura**, Japan,

Connolly, Malaysia, **Jenkins**, Hong Kong, **Jones** and China, **Dong**.

Editorships and editorial boards: staff have been editors/co-editors for four journals (International Journal of Cast Metals Research, **Griffiths**, Chinese Surface Engineering, **Dong**, International Journal of Surface Engineering and Interdisciplinary Materials Science, **Dong** and Sports Engineering, **Strangwood**) and serve, or have served, on eighteen editorial boards (including Corrosion Science Engineering and Technology, Materials Characterisation, Journal of Ironmaking and Steelmaking, International Materials Reviews, Journal of Aerospace Engineering, Sports Technology (IMechE Part P) and Materials Science and Technology).

Lectures, conference organisation and advisory bodies: staff have delivered over 110 invited/keynote/plenary lectures at international conferences, and have participated in over sixty international conference organising committees and national/international advisory committees. Examples of staff involvement in conference organizing committees include those of: Fourth International conference on Superconductivity and Magnetism, **Crisan**; Microscopy of Oxidation 2008, 2011, 2014, **Evans**; Gordon Conference on Aqueous Corrosion 2008, **Davenport**;THERMEC 2013, **Stamboulis**; Corrosion 2010,**Connolly**; International Conference on Thermo-mechanical – processing TMP 2012, **Davis**; International Conference on Structural Health Monitoring, **Fernando**; International Conference on Communication, Networking and Signal Processing, **Fernando**; Eighth European Conference on Superplastic Forming, 2011,**Basoalto, Brooks**; OPTIMoM 2010 and 2014, **Basoalto, Brooks**; Liquid Metal Processing and Casting, TMS 2013, **Ward**; Gamma Titanium Aluminides 2012, 2013 **Hu**; International Conference on Industrial Engineering and Engineering Management (IEEM) 2008, 2009, **Papaelias**; First International Conference on Aerosol Technology 2014, **Chang**; and Euromat 2009, **Dong**. Examples of staff involvement on national/international advisory committees include: Deputy Chair of Science Board (STFC), **Davenport** ; Chair of Graphite Technical Advisory committee (GTAC) to the Office of Nuclear Regulation (ONR), **Bowen**; European Spallation Source (ESS) Scientific Advisory Panel, **Laver**; New US Critical Materials Hub - Washington DC, 2012, **Walton**; Oakridge National Laboratory (ORNL) Scientific Review Committee, **Laver**; Oversight Panel for EDF Energy on type 316 steels, **Evans**; and the Qatar National Research Fund, **Dong**.

Visiting scientists: typically staff host between twelve and twenty visiting scientists at any one time (currently seventeen) and over this period of assessment visits have been hosted by staff including **Book**, **Dong**, **Fernando** for visits supported by EPSRC, The Royal Society, The Royal Academy of Engineering, Japan Society for the Promotion of Science (JSPS) and the UK Foreign and Commonwealth Office/BIUS. Currently, (2012-2016) we have one Royal Academy of Engineering visiting Professor of Innovation in Casting Technology, **Withey,** seconded from Rolls-Royce and who is providing invaluable support in the development of HTRC.

Significant consultancies: staff hold, and have held, some twenty significant consultancies with organisations which include: Rolls-Royce Group plc, **Bowen**; Nuclear Decommissioning Authority, Radioactive Waste Management Directorate (NDA RWMD) and NAGRA, **Davenport**; Tata Steel, **Davis**; TIMET UK, **Ward**; TWI, **Papaelias**; European Space Agency, **Adkins, Attallah**; Messier-Bugatti-Dowty, **Attallah**; Office of Nuclear Regulation (ONR), and DSAC Expert Members Panel, **Bowen**; EDF Energy, **Evans**; and Shell, **Ward**.

Membership of Professional Bodies: most senior staff are members of the EPSRC College and staff hold senior memberships of forty three professional and learned bodies including the Royal Academy of Engineering; Institute of Materials, Minerals and Mining; Institute of Mechanical Engineering; Institute of Physics; Royal Society of Chemistry; NACE International; British Institute of Non-Destructive Testing and Institute of Cast Metals Engineers (ICME). **Davenport** is a visiting scientist at Diamond Light Source and has led the bid for a new beam line (DIAD).

Prizes: staff have also secured thirteen prizes for papers published in this assessment period including; 2013 Guy Benough Award (IOM3), **Davenport**; Best Paper at Eight World Congress on Railways Research (WCRR 2009), **Davis, Papaelias**; British Foundrymen's Medal and Prize (2009), **Griffiths**, Institute of Cast Metal Engineers; 2009 MICRESS Award for Best Engineering Application of a Phase Field Model, **Warnken**; and 2012 T.P. Hoar Prize of the Institute of Corrosion (Corrosion Science Best Paper – 2011), **Connolly**.