Institution: Sheffield Hallam University

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: XeraCarb Limited: a spin-out from Sheffield Hallam University manufacturing novel ceramic composites

1. Summary of the impact

XeraCarb Ltd is a **spin-out company** formed in 2011 to exploit a class of ceramic composite materials co-invented by Jones. These materials were first devised in 2008 via a Materials and Engineering Research Institute (MERI) Knowledge Transfer activity and developed from 2009 onwards through a series of UK Ministry of Defence (UK MoD)-funded research projects. *XeraCarb* was spun out after the underpinning research won a national award in 2011 as the most promising UK materials system for commercialisation. The applications for *XeraCarb*'s materials range from body- and vehicle-armour to kiln furniture and wear-resistant components. **The company has attracted significant venture capital investment and is valued at over £1m.** It has set up an independent production facility, has appointed employees, has been awarded a TSB grant, has materials undergoing trials in respect of a number of applications, and has delivered its first orders.

2. Underpinning research

Jones joined MERI in 2000 as a Senior Research Fellow in the Materials Analysis Group of the Consultancy Centre. In this role he has led a range of contract research projects to analyse and improve the wear resistance of ceramics, coatings and other hard materials. Within this body of work, studies into the properties and performance of Si_3N_4- and SiAlON-based ceramic composites [1,2,3], two of which were submitted under his name to RAE2008, are pertinent to this case study: they underpin Jones' expertise in this field. He was promoted to Principal Research Fellow in 2009 and has been at the University throughout the REF period.

The spin-out *XeraCarb* is founded on research IP, expertise and experience relating to novel material compositions and production processes. The materials involved are silicon carbide ceramic composites in which an alloy of silicon nitride and aluminium oxide (SiAlON) is used as the binder phase. Jones developed these materials with Dr Anthony Pick, an experienced industrial ceramicist, after the two met in 2008 at an outreach event within the *Routes to Innovation* (R2i) Knowledge Transfer (KT) programme (**REF3a(b)**). Pick had worked for 40 years in the industrial ceramics and refractory industry, mostly in the production of silicon carbide refractory products. He had been independently developing research ideas based on his experience prior to 2008. However, it was not until his ideas were combined with Jones' previous expertise in SiAlON-based ceramic composites that the novel aspects underpinning this case study were developed.

The central novelty of Jones and Pick's research relates to the identification of appropriate combinations of SiC, SiAlON and sintering additives required to achieve enhanced materials properties using low temperature (<2000° C) production methods. The key findings relate to ceramic composites made through appropriate combination of SiC, Al_2O_3, Si_3N_4, and 5 other ingredients, including rare earth sintering aids. These ceramics proved realisable using conventional (non-vacuum) furnaces at much lower temperatures than sintered SiC due to utilisation of a reactive sintering route in which SiAlON forms in-situ from Si metal.

The initial feasibility study for this work was conducted in MERI by Jones and Pick in Jan-Mar 2008 using a 3-month seed-corn grant [i] obtained from the R2i KT programme. This study determined composite formulations which significantly out-performed pre-existing commercial grades of a similar composition (e.g. nitride bonded SiC) in terms of density, strength and Weibull modulus. Specifically, Jones and Pick developed new materials that were 10% less dense than sintered SiC and 30% less dense than Al_2O_3, two conventional body-armour materials. Achieving equivalent performance with reduced component weight provides an obvious potential benefit in the context of body-armour panels for military personnel.

The results from the R2i feasibility project provided the basis for a 2009 UK MoD funding application. This led to a 6-month Centre for Defence Enterprise project [ii] conducted in MERI to test the viability of SiAlON/SiC composites, made via reactive sintering, for use as lighter and cheaper armour materials. After a positive evaluation, this was followed (2010) by a further 6-month project [iii] conducted in MERI to make prototype armour components for testing by the MoD's Defence Science & Technology Laboratory (DSTL). This work explored routes by which the new materials could be produced in complex shapes and as large components. The materials were, thus, developed in such a way that they could be easily slip-cast with potential for pressure casting (a more efficient method for scale-up purposes). This proved a critical development in terms of commercial potential, since it made the materials significantly cheaper to produce than sintered SiC and competitive with Al_2O_3. It also opened up a number of alternative applications (see **section 4**). A third 6-month project funded by DSTL (2012) examined the effects of incorporating hard phases (TiB_2, c-BN, B_4C) into the base composite materials [iv].

In order to protect the IP in this work, it was written up first in two patent applications [4,5] submitted in Dec 2012. As set out in **section 4**, this timing and the use of patents rather than refereed papers in the open literature was a requirement for securing investment funding.

Ongoing research work, supported by a £175k TSB SMART Proof of Concept award [v], involves developing and testing grades suitable for a range of abrasive wear and refractory applications. Also, a new research programme on pressure casting, funded by a £284k DSTL grant [vi] and £100k of XeraCarb investment, started in Oct 2013 in partnership with the MoD and other commercial contractors. Most prestigiously, Jones has been awarded a 24 month **Royal Society Industrial Fellowship** to ensure his continued involvement in the XeraCarb venture through a 0.5 FTE secondment over 24 months [vii]

3. References to the research

[1] Jones, A.H., Trueman, C., Dobedoe, R.S., Huddleston, J. and Lewis, M.H., Production and EDM of Si_3N_4-TiB_2 ceramic composites, *British Ceramic Transactions* **100**, 49 (2001)
DOI: 10.1179/096797801681198 12 citations (WoS, Sept 2013)

[2] Jones, AH; Dobedoe, RS and Lewis, MH, Mechanical properties and tribology of Si_3N_4-TiB_2 ceramic composites produced by hot pressing and hot isostatic pressing, J Euro Ceram. Soc. 21, 969 (2001)
DOI: 10.1016/S0955-2219(00)00294-6 31 citations (WoS, Sept 2013)

[3] Jones, A.H., Micro-scale abrasive wear of silicon nitride, SiAlON-TiB_2 composites and D2 tool steel using a multiple load method, *Wear*, **258**, 942 (2005)
DOI: 10.1016/j.wear.2004.09.049 5 citations (WoS, Sept 2013)
KEY REFERENCE

[4] UK Patent Application no. 1222996.9 "Ultra Hard SiC Ceramic." Applicant: XeraCarb. Inventors: Jones and Pick, 20/12/12
Confidential document – available on request from SHU Research and Innovation Office
KEY REFERENCE

[5] UK Patent Application no. 1222995.1 "Rare Earth Oxide SiC Ceramic." Applicant: XeraCarb. Inventors: Jones and Pick, 20/12/12
Confidential document – available on request from SHU Research and Innovation Office
KEY REFERENCE

[i] Routes to Innovation (ERDF / Yorkshire Forward KT Programme) seed-corn grant, PI Jones, £30k, Awarded March 2008

[ii] MOD Contract: RT/COM/7/705, "Lightweight Personal Protection – Development of SiAlSiC, new lightweight ceramic composite armour" PI Jones, £47,800. Awarded 28/10/09

[iii] MOD Contract: DSTLX 1000045258, "Production of full size 12 Osprey Plates, 30 small curved plates and 20 helmet plates" PI Jones, £61,600. Awarded 29/07/10, amended 31/3/11

[iv] MOD Contract: DSTLX 1000065597, "Multi-Component Ceramic Components utilising Ultrahard Phases" PI Jones, £59,725. Awarded 11/01/12

[v] TSB SMART Proof of Concept award (TSB File Ref: 710272) to develop and test materials suitable for a range of abrasive wear and refractory applications, PI Jones, £175k. Start 1/4/2013 for 15 months

[vi] MOD Contract: DSTLX 1000085527, "Lightweight Conformal Ceramic Armour" PI Jones, £284,000. Awarded 08/10/13

[vii] Royal Society Industrial Fellowship IF 120126 to Jones, 50% secondment + research expenses for 2 years (start 1/4/2013)

4. Details of the impact

In addition to scientific expertise, Jones brought essential commercial and KT know-how to this impact. He developed this through extensive engagement with KT activities within MERI, including: 3 years (2009-11) in a 0.5 FTE "KT Champion" role; and leadership of R2i (2007-08), a Yorkshire

Forward and ERDF funded programme for the provision of innovation assistance in materials and engineering to organisations in South Yorkshire (see **REF3a(b)**). In 2008, seed-corn support from the R2i programme [i] funded the feasibility study from which *XeraCarb* developed. Support for the subsequent research phases was garnered through Jones' knowledge of MoD and TSB funding processes and priority areas [ii-v].

In 2011, on the basis of the research described in **section 2,** Jones and Pick won the Worshipful Company of Armourers and Brasiers' (WCAB) Venture Prize [A]. This prize, awarded each year to the UK's most promising development in materials science, carried with it a £25k venture capital investment. This resource, together with a further £75k which it leveraged from Finance Yorkshire ([B,C]), was used **to establish *XeraCarb Ltd* (Company No. 07738054) [D] in 2011 as a spin-out** with the primary purpose of exploiting the IP in Jones and Pick's materials. At this stage, Jones, Pick, SHU, WCAB and Finance Yorkshire [C] were the company's shareholders. During its first 6 months of operation, *XeraCarb* recruited an entrepreneur with substantial experience of successful start-up companies as CEO [E]. In preparation for the next investment round, the IP from the initial research was formally transferred to the company's ownership.

As well as supporting Jones' work within MERI, SHU contributed to *XeraCarb's* development by providing strategic commercialisation management advice. In particular, market research and business planning recommendations provided by the technology transfer staff in the University's Research and Innovation Office (RIO) were instrumental in shaping *XeraCarb*'s progress. The market research, in particular, upgraded the prospects (and the investment potential) of the embryonic company since it identified markets for the new materials beyond the initial focus on body-armour applications.

In September 2012, armed with this market information**, *XeraCarb* attracted a further £550k investment from Finance Yorkshire [C] and two independent investors. This valued the company at ~£1m even before production facilities were in place.** Patent applications were made in late 2012 [4,5] in order to realise the tangible IP required to secure this investment. In holding this valuable IP, *XeraCarb*'s shareholders are identifiable **beneficiaries** of this impact. Again, RIO provided strategic advice and legal assistance in the drafting of these Patents.

In early 2013, *XeraCarb* set up a **production facility** in Barnsley, South Yorkshire and appointed a Plant Manager, Business Development Manager and factory operatives. **These employees are another group of beneficiaries.** Production equipment was installed, in particular a 2m^3 capacity furnace capable of 1500℃, designed by the company to carry out the in situ reaction sintering process.

By July 2013, the company had a board of 5 including a non-exec independent investor, a CEO, 3 FTE employees plus Jones on a 50% sub-contract basis funded by his Royal Society Industrial Fellowship [vii]. Plans were to expand staffing to >8 within the first year of production.

The markets identified by RIO and the progress made within them in the REF impact period were as follows:

(i) Kiln Furniture *Xeracarb*'s materials have good strength which is retained to temperatures of 1400-1500°C. They also possess considerable thermal shock resistance. This combination of properties makes them well-suited to supporting items being heated or fired such as porcelain, sanitary ware and superalloys. The global market for such kiln furniture is $300m, with $100m in the EU. *Xeracarb*'s kiln furniture materials, **Xerabond – KF** [F], have been placed on trial at *Steelite*, one of the UK's leading porcelain manufacturers, and a range of components are available commercially. Agents/suppliers such as *IPS Ceramics* have been in negotiation with *XeraCarb* to supply/stock this kiln furniture.

(ii) Armour XeraCarb's **Xerabond – AP** materials [G] are suitable for use in hard plate armour applications such as bullet proof vests and vehicle armour [H]. The US market is $570m for all armour systems, with the EU plus other global markets approaching a similar size. The UK MoD's DSTL has tested **Xerabond – AP** materials in ballistic scenarios. Test details and results are restricted, but it is pertinent that DSTL has continued to support and encourage the development of the materials and the progress of *XeraCarb*. DSTL has a remit to ensure that the UK retains a reliable and sovereign armour ceramics manufacturing base. Consequently, DSTL is a **beneficiary** of this impact since ***XeraCarb* is the only supplier enabling it to meet this requirement** [J]. Recognising *XeraCarb*'s position as an essential supplier for future UK armed forces capability, DSTL has awarded it a £284k, 2-year contract [vi] to develop pressure-cast versions of the current UK armour system. This work will aim to achieve rapid manufacturing capability and improved material properties and consistency. Requests for trial materials have also been received from eight UK manufacturers of armour systems / armoured vehicles. At the close of the REF impact period, trial components were being tested by three of these manufacturers.

(iii) Abrasion-resistant components/refractory materials Potential products in this category include nozzles and pipe liners for abrasive-materials-handling and gas burner nozzles for furnaces. The market is estimated at >$100m globally. A number of alternative material compositions have been developed, targeted at applications for which cheaper and/or more wear resistant materials are required. Trial wear-tiles have been placed with *Broadbents Ltd*, a major UK manufacturer which supplies centrifugal mineral dewatering machines globally. Wear- and high-temperature-corrosion-resistant grades have also been trialled by *Omegaslate Ltd*. Also, a refractory nozzle supplier (*Melle Ltd*) has requested design and manufacture of test nozzles for gas burner applications. A 15 month TSB SMART Proof of Concept award, with a project value of £175k [v], has been won to develop and test further material grades suitable for a range of abrasive wear and refractory applications.

5. Sources to corroborate the impact

[A] Worshipful Company of Armourers & Brasiers Venture Prize, £25,000, 2011
http://www.armourershall.co.uk/venture-prize-winners/

[B] Case study on *XeraCarb* on Finance Yorkshire website, including .pdf leaflet
http://www.finance-yorkshire.com/case-studies/xeracarb.asp

[C] Finance Yorkshire representative, corroborating source 1

[D] XeraCarb website http://www.xeracarb.com/

[E] CEO of XeraCarb Ltd, corroborating source 2

[F] http://www.xeracarb.com/workspace/u/d/kiln_furniture_data_sheet_150713.pdf

[G] http://www.xeracarb.com/workspace/u/d/xc_armour_data-_sheet.pdf

[H] Ballistic Trials Consultant, corroborating source 3

[J] MoD DSTL representative, corroborating source 4