Institution: Cardiff University

Unit of Assessment: UoA17 Archaeology

Title of case study: Evidence based management strategies for Heritage iron

1. Summary of the impact

Most museums in Britain contain collections of archaeological and heritage iron objects that are rapidly rusting away due to an absence of evidence-based management strategies for their display and storage. Research at Cardiff University has identified the corrosion mechanisms driving the destruction of this iron and, through experiment, has quantified the effectiveness of desiccation and chloride desalination treatments either to prevent or slow its corrosion. The research has led to the development of clear guidance for devising, implementing and managing preservation strategies for iron. These have been adopted by English Heritage, the British Museum and other institutions. The guidelines underpin an imaginative use of desiccation to preserve Brunel's iron ship ss Great Britain as an international heritage attraction, centre for research and academic study of Brunel and a significant contributor to local and national economies.

2. Underpinning research

Corrosion is an electrolytic process occurring in marine and buried archaeological iron supported by chloride drawn into the metal from its surrounding environment. Post-excavation this soluble chloride and atmospheric moisture drive fresh corrosion. While chloride removal or environmental desiccation can prevent this, their implementation has long been empirical; the 'no-corrosion' relative humidity value for chloride infested iron was unknown and the effectiveness of chloride extraction methods was un-quantified. Cardiff research has and continues to address both these unknowns.

Desiccation: corrosion mechanisms at low relative humidity

A 1999 study coordinated by Eura Conservation with specialist input that included Cardiff University, showed corrosion would make the world famous iron hull of the ss Great Britain, housed in dry dock in Bristol, physically unviable as a visitor attraction within 25 years. Its length and bulk (325 feet) meant that encasement in a desiccated environment was the only practicable conservation option. At that time reaction routes and corrosion rates of iron at low relative humidity were little understood, as was the impact of hygroscopic chloride bearing akaganéite and ferrous chloride corrosion products, which form during drying of iron, and were identified on the ss Great Britain and archaeological iron undergoing post-excavation corrosion. Laboratory studies in Cardiff quantitatively identified that akaganéite and ferrous chloride facilitate iron corrosion at low relative humidity. Experiment identified that corrosion ceased at 12% relative humidity and was detectable at 15%, but without significant impact on corrosion rate until 35% relative humidity (**3.1; 3.2**). This data set clear environmental parameters for controlling corrosion of chloride infested iron.

Chloride removal from iron

The effectiveness of aqueous deoxygenated alkaline solutions for desalinating iron was quantified by major research individually treating 150 archaeological iron objects with controlled variables to identify optimum conditions for chloride extraction (**3.3**). Measuring both the chloride removed during treatment and the chloride retained within objects post-treatment, made it possible to statistically calculate chloride extraction effectiveness. Additionally, quantitatively recording pre- and post-treatment corrosion rates of selected iron objects revealed how chloride extraction reduced corrosion rates (**3.4; 3.5**) and facilitated development of new theories on how post-treatment residual chloride influences object corrosion rate (**3.5**). Management concern that treatment chemicals created future corrosion risks was addressed by studying their interaction with iron at high RH, concluding that risk was negligible (**3.6**).

Answering the ss Great Britain desiccation questions was supported by HLF funding, with experiment led by Professor David Watkinson and his Research Assistant Mark Lewis (1999-2009), who gained a PhD from the study. An AHRC Collaborative PhD Studentship (Melanie Rimmer, 2007-10; AHRC EPSRC research associate 2010-2013) between Cardiff University (Watkinson Supervisor) and the British Museum (Dr Quanyu Wang) quantified chloride extraction and designed treatment application for a museum context. Heritage sector professionals consider

Cardiff research *"leads the way on testing several of the hypotheses of how heritage iron can be stabilised for storage."* (**5.5**). The award of the Gulbenkian Museum Prize to ss Great Britain in 2006 recognised its innovative conservation and underpinning science. Chief judge Professor Lord Robert Winston commented '… *a truly ground breaking piece of conservation*…' making the ship '…*accessible and highly engaging for people of all ages*' (http://www.thegulbenkianprize.org.uk/press/prwinner2006.htm). In 2010 Watkinson was awarded the Plowden Medal for *'innovative research and services to conservation'* as a direct result of his work on the iron corrosion.

3. References to the research

3.1 Watkinson D. and Lewis M. (2005) Desiccated storage of chloride contaminated archaeological iron objects. *Studies in Conservation*, 50, 241-252. ISSN: 00393630

3.2 Watkinson D. and Lewis M.R.T. (2005) The Role of βFeOOH in the Corrosion of Archaeological Iron. In Vandiver P.B., L. Mass J.L., and Murray A. (eds.) *Materials Issues in Art and Archaeology VII*. Warrendale, PA, Material Research Society Symposium Proceedings 852, 001.6. Official URL: http://dx.doi.org/10.1557/PROC-852-OO1.6. ISBN: 9781558998001

3.3 Rimmer, M., **Watkinson D.** and Wang Q. (2012) The efficiency of chloride extraction from archaeological iron objects using deoxygenated alkaline solutions. *Studies in Conservation*, 57, 29 - 41. URL: http://www.ingentaconnect.com/content/maney/sic/2012/00000057/00000001/art00003. DOI 10.1179/2047058411Y.0000000005

3.4 Rimmer, M., **Watkinson D.** and Wang Q. (2012) The impact of chloride desalination on the corrosion rate of archaeological iron. *Studies in Conservation*. URL: http://orca.cf.ac.uk/32146/. DOI 10.1179/2047058412Y.0000000068

3.5 Watkinson, D. (2010) Measuring the effectiveness of washing methods for corrosion control of archaeological iron: problems and challenges*. Corrosion Science Engineering and Technology*, 45 (5), pp. 400- 406. Official URL: http://dx.doi.org/10.1179/147842210X12754747500801. DOI 10.1179/147842210X12754747500801.

3.6 Rimmer, M. and **Watkinson, D.** (2011) *Residues of alkaline sulphite treatment and their effects on the corrosion of archaeological iron objects.* In P. Mardikian, C. Chemello, C. Watters and P. Hull, (eds.) METAL 2010, Proceedings of the Interim Meeting of the ICOM-CC Metal Working Group, Charleston, South Carolina 11-15 October 2010, Clemson University (2011) pp. 16-22. ISBN: 9780983039921. Available from www.lulu.com.

Grants

£42,000. Granting body ss Great Britain Trust, Watkinson 2001-3.
£59,000. AHRC Collaborative Studentship, Watkinson 2007-10.
£367,000. AHRC/EPSRC Science and Heritage Large Grants Award, Watkinson 2010-13.
£62,000 AHRC Collaborative Research Training Grant, Watkinson 2012-15.

4. Details of the impact

Outputs have established guidelines and changed thinking at formative and operational levels for conservation of iron within the heritage sector.

Introduced to the sector

- Best practice guidelines for:
  - desiccated storage of chloride infested heritage iron
  - de-chlorination of archaeological iron
- Corrosion control as a management concept for conservation
- Quantitative research to underpin management and cost-benefit analysis

Brunel's ss Great Britain – case history of research in practice

- Provision of a predictive tool for managing the preservation of the ship
- Predictive survival to enable commercial and social exploitation of ss Great Britain

Desiccated Storage

Evidence from Watkinson's research team has developed desiccated storage into the first quantified evidence based method for preventing and controlling the corrosion of archaeological iron within the heritage sector. Dissemination of their research to the heritage sector is via publication and over 19 conferences (**5.1**) with citation in BS; PAS198:2011 '*Specifications for Environmental Conditions for Cultural Material'* (**5.2**) and collaboration with English Heritage producing '*Guidelines for the Storage and Display of Archaeological Metals'* (**5.3**) which is designed to guide end-users in decision making and best practice. For the first time evidence-based management of museum-based archaeological iron is possible. Impact in a broader context has also been pursued within corrosion science arenas (**5.4**).

Managing preservation of vast collections of archaeological iron in museums (**5.5; 5.6**) is challenging. Outcomes from Cardiff research, "*have allowed end-users, including the British Museum, better to apply evidence-based conservation treatment and management strategies to the preservation of these vulnerable collections*" (**5.6**). The Museum of London (**5.5**) notes how it, "*enabled us to implement and manage desiccated storage of tens of thousands of archaeological iron objects with predictive understanding of its effectiveness and outcomes."* Cardiff data on corrosion rates below 35% relative humidity guides silica gel desiccant replacement strategies for the small plastic boxes in which the bulk of archaeological iron is stored worldwide, allowing managers to assess corrosion threats, determine risk and "*assess the most cost effective ways of maintaining our large collections of this material by desiccated storage."* (**5.5**). Thus time consuming renewal of gel in thousands of boxes can now be planned according to the risk-level managers are prepared to adopt; either no corrosion (frequent gel changes) or minor corrosion (changing gel before box interiors reach corrosion escalating 35% relative humidity). Similarly, for fully desiccated storerooms, relative humidity targets can be set either to prevent or to control corrosion, according to what constitutes acceptable cost. Importantly, Cardiff research offers clear guidelines on 'safe' relative humidity values to guide end users to calculate costs of storage with confidence (**5.6**).

Desalination

Quantification of desalination treatments and work on how they impact on corrosion rate of iron post treatment offers data for users, "*to decide whether their use will offer cost benefit in terms of improved object lifespan for the use of staff time and resources."* (**5.5**). This links directly to management strategies developed by museum curators to optimise resource use and forward plan (**5.5**).

Preservation of ss Great Britain

Cardiff research into low humidity corrosion *"dramatically turned the fortunes of the ship around and demonstrated that such large heritage items can be conserved and preserved, as well as being brought to life for the enjoyment and education of the general public"* (**5.7**). It facilitated cost-benefit analysis and offered a heritage management tool for ss Great Britain (**5.8**). It is recognised that, *"delivering an evidence based preservation strategy allows ss Great Britain to predict the survival of the ship and develop a long-term business plan with real confidence"* (**5.7**). By controlling corrosion with a 20% relative humidity operational target, rather than preventing it occurring by implementing lower humidity controls, introduces the novel and pragmatic concept of aligning object lifespan with resource availability. This offers a new management concept to conservation; hitherto, corrosion prevention was inevitably the preservation goal. It also provides for flexible management, as when money is plentiful an increased spend on fuel can reduce relative humidity in the controlled space and lengthen the ship's lifespan, additionally any potential impact of climatic control failure on corrosion rate can be predicted.

Survival of the ss Great Britain produces considerable social and economic benefits for the city of Bristol. The ship is the number one visitor attraction there thanks to the "*innovative conservation project built upon the principles and parameters developed by Cardiff"*(**5.7**) The Trust turns over £4m p.a., contributes £9m p.a. to the Bristol economy, and is a major employer (172 posts) (**5.7**). Pre-conservation visitors numbered 70,000 per annum (2004) compared to 170,000 (2010) with 15,000 plus venue hire guests (2010) and many school visits (**5.7**). The intangible impact of 'sensation and visitor experience' is reflected by visitor reviews, and this is only made possible by the on-going and displayed conservation process (**5.7; 5.9**). Tourism brings in 52% of visitors from outside the region, with 48% of these in hotel accommodation. Calculable survival of the ship acted as a focus for the creation of the Brunel Centre in 2010 (**5.10; 5.7**), which houses a conference centre, display area and a Brunel archive for records from Bristol University, with apartments above providing added income. These achievements are recognised by many national and international awards since 2006, which have only been made possible by successful conservation of the ship (**5.7**).

Engineering applications for the corrosion data have been sought via collaboration with Flint Neil Engineers, with access to examine historic and modern bridges being planned, starting with Brunel's Clifton Suspension Bridge to determine if corrosion products there reflect a chloride driven corrosion mechanism. A successful AHRC/EPSRC Science and Heritage grant application (£367,000) by Watkinson is refining and extending the existing predictive preservation model developed in Cardiff by quantifying real time corrosion of archaeological iron as a function of humidity, chloride content and corrosion damage to objects measured as iron loss and heritage value. Cardiff University was approached by Historic Scotland to determine best practice for the preservation of historic wrought iron and has two PhD projects (one AHRC and one Historic Scotland funded) working to this end.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1. *Indicative examples of conference presentations to heritage sector professionals:* Watkinson, D. and Rimmer, M. 'Quantitative research and heritage management: Ferrous metals' Technoheritage: Science and Technology for the Conservation of Cultural Heritage, Santiago de Compostela, Spain, 2-5th October 2012. URL: http://www.fokus-gmbh-leipzig.de/pdf/Abstract-e-book_of-All-Participants.pdf.
Impact claim summary: delivery direct to heritage practitioners and export of procedures.

5.2 BS; PAS198:2011 '*Specifications for Environmental Conditions for Cultural Material'* (31 May 2011) ISBN 978 0 580 71315 6.
Impact claim summary: National standard citing Cardiff data as set points.

5.3. Thickett, D, Rimmer, M and Watkinson, D. (2013) *Guidelines for the Storage and Display of Heritage Metals.* Swindon, English Heritage. **Impact claim summary**: Guidelines for applying practices based on Cardiff research in the UK heritage sector.

5.4. Watkinson, D. (2013) Conservation, corrosion science and evidence-based preservation strategies for metallic heritage artefacts. In Dillmann, P., Watkinson, D., Angelini, E and Adriens, A. *Corrosion and Conservation of Heritage Metals (Part 1)*. European Corrosion Federation Green Book Series number 65. ISBN: 1 78242 154 8. **Impact claim summary**: Corroborates dissemination beyond archaeological contexts to corrosion scientists within the ECF.

5.5. Head of Conservation and Collection Care, Museum of London. Testimonial (12 July 2013). **Impact claim summary**: Cites adoption of outputs from Cardiff research into management and treatment practices within the *Museum of London Archaeological Archive and Research Centre*.

5.6. Keeper Department of Conservation and Scientific Research at the British Museum. Testimonial (4 July 2013)**. Impact claim summary**: Cardiff research influences conservation, management and cost-benefit strategies for archaeological iron in the British Museum

5.7. Director and Chief Executive of ss Great Britain Trust. Testimonial (16 July 2013). **Impact claim summary**: Cardiff research underpins the preservation of the ss Great Britain and thereby the development of on-going business planning and the social and economic impacts that emanate from their success.

5.8 Watkinson, D and Tanner, M. (2008) *s*s Great Britain: conservation and access – synergy and cost. In Saunders, D., Townsend, J. and Woodcock, S. *(*eds) *Conservation and Access; contributions to the London Congress,* 15-19 September 2008. London, The International Institute for the Conservation of Historic and Artistic Works, pp. 109-114.
Impact claim summary: Research delivered a management tool for ss Great Britain.

5.9. http://www.tripadvisor.co.uk/Attraction_Review-g186220-d206438-Reviews-Brunel_s_ss_Great_Britain-Bristol_England.html **Impact claim summary**: evidence for intangible measurement of pleasure and well-being derived by visitors.

5.10 http://www.ssgreatbritain.org/brunel-institute/collections **Impact claim summary**: Conservation of the ship made the development of this centre possible.