Institution: University of Nottingham

Unit of Assessment: 15 General Engineering

Title of case study: Use of novel small specimen testing methods for improvements in power plant maintenance operations

1. Summary of the impact

A range of small specimen creep testing methods have been developed through research carried out at the University of Nottingham (UoN). These tests are being used in the following ways: RWE npower has used the impression creep test on approximately 180 samples taken from its power plants in the UK, France and Holland; AMEC has installed two impression creep test rigs for testing nuclear power plant materials for a range of EDF Energy power plants; Laborelec is using the small ring techniques for evaluating nickel based super alloys in turbine blades for clients in Belgium and Holland and the Electrical Power Research Institute (EPRI) has used the small specimen techniques, with the assistance of UoN, on power plant structures in the USA.

2. Underpinning research

“Creep” is a feature found in the vast majority of power station failures in the UK and worldwide. This is because the combination of stress, temperature, and pressurisation over time results in a degradation of material properties, especially where two parts are welded together. If creep is not monitored and mitigated it can lead to catastrophic failure, including the bursting of steam pipes or boilers, resulting in millions of pounds of lost revenue on top of the cost of repairing the damage.

It is in this area that UoN’s Tom Hyde (Professor of Mechanical Engineering, UoN, 1978 - present) and Adib Becker (Professor of Mechanical Engineering, UoN, 1990 - present) have focused an important part of their research**.** The work was initiated in 1996 through an EPSRC-funded three-year project aimed at developing a procedure for assessing the performance of repaired welds at elevated temperature [Grant P1]. This research was carried out with industrial collaborators EDF Energy, National Power (later merged with RWE to become RWE npower) and PowerGen. It involved the UoN team developing new mathematical models of material behaviour and incorporating these into Finite Element codes [2.1]. This was followed by experimental studies on the behaviour of repaired welds at high temperatures (up to 640 celsius), resulting in new holistic methods for the prediction of creep failure in welds operating at high temperatures.

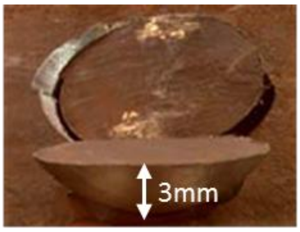

Figure 1: Scoop sampling in progress (left), extracted scoop sample (right)

The success of the above project resulted in further EPSRC funding for research into the structural integrity of power plant welds and plant life extension, again with the leading power plant operators [P2, P3, P4, P5]. These projects – carried out between 2000 and 2012 – enabled the UoN team to combine individual expertise in Finite Element (FE) modelling, metallurgy and material science. Again, the research provided a route to engaging with the leading power plant operators in the UK and their parent companies in Europe**.**

In this series of research projects UoN performed the Finite Element modelling of creep crack growth and fundamental analysis of the parent, weld and heat affected zones in welds [2.2, 2.3] and then assessed residual life to determine the power plant structural integrity [2.4]. Outcomes included an understanding of where reliable samples of material could be taken without compromising the weld, and innovative methods for extracting and testing the samples.

The sampling techniques developed through this research enable tests on miniature specimens machined from “scoop” samples removed from the components (Figure 1). Two such specimen tests – the Impression Creep Test (ICT [2.5]) and the Small Ring Test (SRT [2.6]) – were developed as a direct result of the research. Both tests have mechanics-based procedures for interpreting the results obtained from them, meaning that once the samples have been taken using the sampling methodologies the actual tests can be performed on standard universal tensile testing machines, which are in widespread use**.**

3. References to the research

Publications *(Items marked with an asterisk indicate 3 most significant papers);*

2.1 Hyde, T.H, Sun, W. and Becker, A.A., 1997, Creep continuum damage constitutive equations for the base, weld and heat-affected zone materials of a service-aged 1/2Cr1/2Mo1/4V:21/4Cr1Mo multipass weld at 640 degrees C, *Journal of Strain Analysis for Engineering Design*, 32 (4), 273-285 DOI: 10.1243/0309324971513409, copy available on request.

2.2 Hyde, C.J., Hyde, T.H., Sun, W. and Becker, A.A., 2010, Damage mechanics based predictions of creep crack growth in a 316 stainless steel, *Engineering Fracture Mechanics*, 77 (12), 2385-2402 DOI: 10.1016/j.engfracmech.2010.06.011

2.3 Hyde, T.H., Saber, M. and Sun, W., 2010, Testing and modelling of creep crack growth in compact tension specimens from a P91 weld at 650ºC, *Engineering Fracture Mechanics*, 77 (15), 2946-2957 DOI: 10.1016/j.engfracmech.2010.03.043

2.4 *Sun, W., Hyde, T.H. and Brett, S.J., 2008, Application of impression creep data in life assessment of power plant materials at high temperatures, *Journal of Materials: Design and Applications*, 222, 175-182 DOI: 10.1243/14644207JMDA183

2.5 *Hyde, T.H., Sun, W. and Becker, A.A., 1996, Analysis of the impression creep test method using a rectangular indenter for determining the creep properties in welds, *International Journal of Mechanical Sciences*, 38, 1089-1102 DOI: 10.1016/0020-7403(95)00112-3,

2.6 *Hyde, T.H. and Sun, W., 2009, A novel, high sensitivity, small specimen creep test, *Journal of Strain Analysis*, 44 (3), 171-185 DOI: 10.1243/03093247JSA502

Grants:

P1 EPSRC GR/L14930/01, 1996-1999: The development for a procedure for assessing the performance repaired welds at elevated temperature (ercos) (PI Hyde)

P2 EPSRC GR/N10011/01, 2000-2003: Structural integrity of high temperature welds in power generation plant (PI Hyde)

P3 EPSRC GR/N63444/01, 2000-2003: Establishment of an academic-industrial network in electricity supply research (PI Hyde)

P4 EPSRC GR/S86334/01, 2004-2008: SUPERGEN 2 - Conventional Power Plant Lifetime Extension Consortium (PI Hyde)

P5 EPSRC EP/F029748/1, 2008-2012: SUPERGEN 2 - Conventional Power Plant Lifetime Extension Consortium – CORE (PI Hyde)

4. Details of the impact

The small specimen creep testing methods developed by the UoN research team have been used by at least four major organisations serving the power industry – either directly (RWE npower) or by providing services to power plant operators (Laborelec, AMEC and EPRI). These companies have benefited through improving the performance of existing plants or preventing potential future losses. Training and consultancy provided by the UoN team in the use of the new tests have resulted in changed industry practices.

The full economic value of the impact to the power industry is reflected through avoidance of cost. Steve Brett [4.1] confirmed that for this reason, the power industry is unable to quantify the total cost of incidents avoided through use of these methods. The following examples provide an indication of the reach and significance of the impact.

The impression creep testing method developed as part of the original research has been used by RWE npower (turnover €50.7Bn, operating in 17 countries) since 2008 for plant life assessment and targeted maintenance in steam-carrying boiler pipes in the UK, France and the Netherlands. Although it is difficult to estimate the full monetary impact of the technology, over 180 tests have been performed to date on power plants in the UK. A specific example of the use of this method and the resulting prevention of cost at RWE npower was provided by the then Corporate Engineer Materials and Welding at RWE npower, Steve Brett, in March 2013:

Chromium Molybdenum Vanadium (CrMoV) Steam Pipe Bend

"Cracking was found on a number of bends on the CrMoV steam pipework systems at several UK power stations. The bends had all been replaced at some stage in the station life and had apparently not been manufactured in the same way as the original bends (many of which were still operating) in these systems. RWE npower identified one bend with a suspect microstructure and in June 2010 carried out small-scale sampling as part of further investigation. Impression creep testing at Nottingham University showed the creep strength of the bend material, although relatively weak, to be no weaker than material in the adjacent original bends. On the basis of this it was decided to leave the bend in service, albeit with an increased inspection regime. A new bend would have cost an estimated ~£40k. The cost of a steam leak from a CrMoV pipework system varies with the time of year. The average cost has been estimated to be ~£200k, but the cost at a time of peak winter electricity demand may be closer to £1M." [4.1].

Other direct beneficiaries of the research include AMEC, one of the world's leading engineering and consultancy services in the oil and gas market, with a turnover £4.1Bn and operations in 34 countries. AMEC has installed two impression creep test rigs in its Risley laboratory and since 2011 has used them to undertake a range of tests on high-temperature materials for major power companies in the UK, including EDF nuclear power plants [4.2].

Since 2010 Laborelec, a technical service provider for the electrical power and energy industry (turnover €48M, operating in 4 countries), has been using the small ring test on virgin nickel based superalloy material used in gas turbine blades for power companies in the Netherlands and Belgium. Laborelec's expert on structural integrity assessments, Steve Nardone, has remarked: "The small-ring test technique has proved its value by providing robust creep data compared with conventional uniaxial data. Alongside conventional uniaxial creep testing and in support of it, the small-ring testing technique can refine our creep assessment and therefore improve our remaining life assessment techniques, which could optimise maintenance and replacement of equipment in the near future." [4.3].

The original research conducted at UoN has resulted in an international reputation for the academics involved. They have widely shared their knowledge with members of the US-based Electric Power Research Institute (EPRI), which has more than 1,000 members worldwide, mainly working in electricity generation and delivery. The UoN team has trained member companies since 2011 to enable them to perform impression creep tests. This has translated into tests being performed in power plants across the USA, and the data generated from these tests has resulted in EPRI funding of two projects at UoN (value USD$120k) on the interpretation of small punch test data.

The research outcomes have been made available to other practitioners through two workshops and one seminar. An International Practitioners Meeting was organised in March 2011, an International Expert Group Workshop in June 2011 and an IMechE Seminar in February 2012, at the University of Nottingham, on small specimen testing, which attracted more than 20 senior level decision makers from the power industry based in the UK, France, Belgium, Finland, the Netherlands and the USA.

5. Sources to corroborate the impact

4.1 Statement from Steve Brett, now retired from RWE npower available on file

4.2 Statement from Andrew Wisbey, Section Leader, High Temperature Materials, AMEC available on file

4.3 Statement from Steve Nardone, Structural Integrity Assessment & Monitoring, Laborelec available on file