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107

Baltica IX

International Conference on Life Management and Maintenance for Power Plants – Abstracts

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Baltica IX

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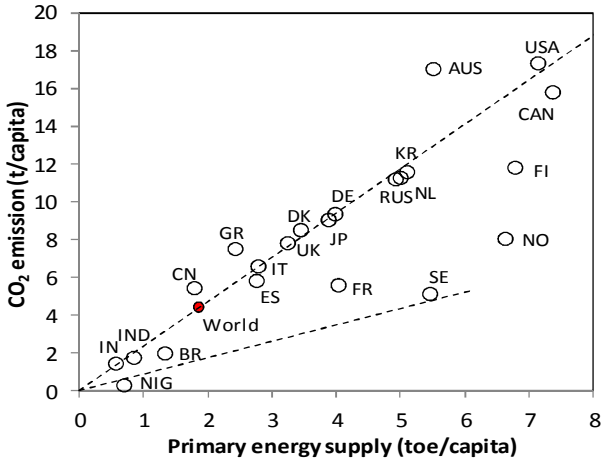
Preface

Since 1988, the triannually organised Baltica Conferences have witnessed continuous change in the environment of operating and maintaining power plants, and Baltica IX in 2013 is no exception. The first conference took place two years after the Chernobyl accident, and although new nuclear plants are again under construction even in Europe, the trouble in Fukushima has revealed risks that needed to be addressed. The accelerating use of coal in the fast growing parts of the world, and new availability of fracking gas has resulted in increasing reliance on fossil fuels in spite of simultaneous emphasis on renewables. The rate and direction of change are making it very difficult to reduce the atmospheric CO_2 content from the present to the target level of 450 ppm any time soon. Even if we must prepare for rising seawater, future policies will retain countermeasures. What is needed is better technology to remove or fully recycle millions of tons of CO_2 per TWh produced, or equivalent capability for alternatives not releasing CO_2.



Reliance on fossil fuels is characteristic to most countries

However, the shift towards more renewables like wind and solar power will also mean more fluctuation in the supply, and a challenge of compensating with other capacity and avoiding heavy subsidies. The issues are far from solved by the current technology and policies, and also show much regional variation. At the same time, not unlike in the issues addressed in the previous Baltica Conferences, existing capacity is ageing and may require attention for example with extended operational timescales, or with new materials, fuels, structures or process solutions.

The editors wish to thank all authors, reviewers, organisers and the Board of the Conference for their invaluable help in preparing for the event and the proceedings. Financial and other contributions by the supporting and sponsoring organisations are also gratefully acknowledged.

Pertti Auerkari & Juha Veivo

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Development of future power plants – demand and challenges

Rudolph Blum

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Abstract

Worldwide Increasing demand for sustainable energy calls for flexible solutions depending on the local conditions. Even wind power and solar energy capacity are expanding all over the world high efficient fossil fuel power plant will continue to be the basic concept in development countries where the need for new energy is large and coal is cheap. The potentials for improved coal fired plants are revealed. In the western countries especially Europe the massive increase in renewable energy is challenging the future energy system and high degree of flexibility may only be establish in the long run using gas turbines as back up for the intermitting out put from wind and solar generation.

Notes

Risk-Based Inspection (RBI) in fossil-fuel fired power plants: Developing further the EU approach and applying it in the large-scale projects

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Abstract

The paper highlights the practical aspects of further development and practical application of the EU approach set up in CWA 15740:2008 document, with special emphasis on critical components in large fossil-fuel fired power plants. Further development of the concept involves (a) primarily economic analysis and includes aspect related to NPV (net present value) and CAPEX/OPEX (capital/operational expenditure), (b) further development of the concept of CWA 15740:2008 towards a European standard (EN), and (c) embedding the concept in the overall concept of aging management. The first development is implemented within the assessment methodology applied by Steinbeis Advanced Risk Technologies, the second one in a multi-client project involving currently a dozen of industrial parties and coordinated by the Dutch standardization body (NEN), and the third one is part of the EU Coordination project. Overall concept has been practically applied in a number of power plants, among others, is currently being applied in power plants in South Africa.

Notes

Similitude of residual stresses and the warm pre stress effect

Kim R. W. Wallin

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Abstract

A material's apparent fracture toughness, at a specific temperature and loading rate, is affected by two factors: residual stresses and the so called Warm Pre Stress (WPS) effect. Residual stresses are global stresses, independent of a pre-existing flaw. They are generally due either to welding or thermal loads, but can also be introduced by plastic deformation. The WPS is due to a local plastic deformation of the material in front of a crack. The residual stresses can be either detrimental or beneficial, whereas WPS is always beneficial. Despite their different nature and origin, they do show a similitude on the apparent fracture toughness response. This similitude is highlighted here.

Notes

French Ageing Management Program in connection with IAEA Safety Guides

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Abstract

During the past 15 years many works have been done on Ageing Management Program (AMP) of Safety classed components in EDF.

The paper will describe all the different aspects concerning these programs, and in particular the EDF step by step procedure and the major results.

To-day, EDF is starting the 3rd ten-year shutdown of all these 3-loop plants (34 plants). During the associated Safety Review, a specific task is devoted to ageing effects and control of all the safety concerned components. A large list of components has been reviewed: mechanical, civil engineering, instrumentation and control, cables, non metallic components. Few non safety but important in term of availability components are considered, like turbine or some balance of plant components. A general review of results and difficulties for 40 and 60 years are presented in the paper.

The second part is devoted to a short review of our procedure with IAEA guidelines.

The third part will shortly describe the associated R&D program for metallic components and knowledge management associated to AMP.

The major conclusions are clearly supporting the needs of international basic procedure and harmonization on the major topics.

Notes

Fatigue of stabilised steel in NPP primary piping − discussion on design curves

Jussi Solin

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Abstract

The ASME Code Section III fatigue design methodology is based on local strain approach and transferability of material performance measured using small scale laboratory samples. Strain controlled tests data shall be transferred to fatigue assessment in a compatible way to provide relevant prediction and follow-up of fatigue usage. Transferability to real components is secured by appropriate margins and full scale testing. Transferability can be studied and improved through better simulation of component operation conditions such as loading mode and sequence, temperature and environment. But the design curves shall be based only on standard tests compatible with the design procedure.

A new design curve for stainless steels has been adopted into the ASME Code Section III. However, it is suspected that derivation of the curve is not fully compatible with the design procedure. Variable temperature data has been mixed inappropriately. Furthermore, the code curve is not applicable to all grades of stainless steel. This paper reports contradictory data for stabilised austenitic stainless steels extending up to 10 million cycles. Niobium and titanium stabilised stainless steel specimens were sampled from 100% relevant material batches fabricated to be used in NPP primary piping.

Fatigue tests periodically interrupted for holds indicated time and temperature dependent hardening during holds at 25°C to 325°C. Notable extension of fatigue life was measured when loading patterns consist of cyclic deformation in lower temperatures than hold annealing. Many NPP piping thermal transients separated by normal operation belong to this category and fatigue assessment based on standard fatigue data seems to underestimate fatigue endurance.

Notes

Effect of initial flaw and load assumptions on risk estimate changes

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Abstract

This study concerns the effect of initial flaw and load assumptions on nuclear power plant (NPP) piping component failure probability and risk estimate changes. As the main criterion for the acceptance of a risk informed in-service inspection (RI-ISI) program is that the overall risk shall not increase when moving from the earlier ISI program to the risk informed one, means for robust quantification of the change in risk are needed. Worldwide, several assumptions and recommendations have been published both for NPP pipe weld initial flaw distributions and welding process induced residual stresses (WRSs), the latter being often the dominant load component for welds. Failure potential and risk analyses were performed with probabilistic fracture mechanics code VTTBESIT and Markov process application for three representative NPP piping welds, covering a wide range of initial flaw and load assumptions. The considered degradation mechanism is stress corrosion cracking (SCC). In the light of the analysis results, it can be concluded that both the size distributions of the initial cracks and WRSs have a remarkable impact on the risk values. The larger the initial cracks and higher on the tensile side the WRSs, the higher the resulting risk values, and vice versa.

Notes

NB-3650M fatigue calculation procedure

Paul Smeekes[1], Eero Torkkeli[2], Mårten Perklén[2] and Otso Cronvall[3]

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Abstract

Fatigue is considered a significant long-term degradation mechanism for safety significant pressure equipment in nuclear power plants. The ASME Section III [1] procedure aims to prevent formation of fatigue cracks during the specified service period. Practical experience gathered during tens of years with hundreds of reactors has shown that the ASME methodology functions very well or is even conservative. Several studies performed in the USA and Japan indicated significant environmental effects on the fatigue as compared to fatigue without environmental effects. This has yielded a methodology as described in the NUREG/CR-6909 [2] and the JSME S NF1-2006 [17]. This methodology should obviously be applied on a best estimate fatigue analysis with reasonable safety factors. Due to the fact that such an analysis is not available and as the ASME methodology functions well this methodology is applied in conjunction with the ASME methodology. Obviously this is conservative, possibly even far overconservative.

From an analytical point of view the NB3600 (engineering approach) and NB3200 (detailed 3D analysis) fatigue analysis methodology and the one in the NUREG/CR-6909 (full time history) are not compatible. In the work presented here a methodology was developed to combine these methods.

Notes

Weld repair simulation for the Mock-up 2 of EU FP7 STYLE Project

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Abstract

The Mock-up under study is fabricated of austenitic stainless steel with additions of vanadium and niobium to increase its high temperature strength. The Mock-up comprises two pipes welded together to produce a pipe section of 600 mm overall length. After completion of the girth weld, deep weld repair was inserted into the girth weld.

Abaqus finite element code was utilised in the welding simulation. Part of the input data was generated with in-house codes. Sequential thermal and mechanical analyses were performed with small strain and displacement formulation. In the mechanical analysis, mixed hardening material model and an anneal temperature of 1100°C was assumed. Symmetry conditions were utilised to reduce the size of the model.

The comparison of computed and measured temperatures and stresses shows good agreement. The computed hoop stress at the repair mid-length was higher than axial stress. Both stresses were tensile through the wall thickness. Confidence in the results was also gained as the results were compared to those presented in literature for a repair welding case.

Notes

Fracture mechanical characterisation of ferrite-austenite dissimilar metal welds (DMWs) for elevated temperature service in view of metallurgical mis-match

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Abstract

A characteristic feature of dissimilar metal weld (DMW) is the metallurgical and material property *mis-match* resulting from a steep gradient of microstructures with significantly different strength and toughness properties. This *mis-match* inevitably affects the entire failure behaviour of DMWs under external operational loads, not only from crack initiation standpoint, but especially regarding the development of crack driving force accentuating *crack path deviation* and subsequent crack growth. The determination of relevant *fracture toughness properties* for all the different microstructural regions of the DMW is of utmost importance for successful structural integrity and lifetime analyses. This paper deals with experimental material characterisation of two configurations of ferrite (SA508)–austenite (Type 304/316) DMWs made using (i) a beveled V-groove and Alloy 82/182 filler metal with a buttering layer and (ii) a narrow-gap weld and Alloy 52 filler metal without any buttering. Results of hardness surveys and fracture mechanical (J-R curve) tests are presented and analysed. The role of mis-match (i.e. metallurgical constraint) in e.g. promoting sudden crack path deviations is discussed in the light of detailed *post-test sectioning metallography and specimen fractography* identifying the actual crack initiation and propagation path.

Notes

General corrosion and SCC tests on ODS steels in supercritical water

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Abstract

General corrosion tests and slow strain rate tensile tests (SSRT) were done on 9–20% Cr oxide dispersion strengthened (ODS) steels in supercritical water at 550 and 650°C with 100–150 ppb dissolved oxygen. Based on the results, Al-alloyed high Cr ODS steels PM2000 and MA956 have superior corrosion resistance when compared to 9–14% Cr ODS steels. In SCW at 550°C and above, it is considered that the minimum Cr-content for thin walled components should be higher than 14%. The results indicate that the ODS steels are less susceptible to stress corrosion cracking (SCC) than austenitic stainless steels or Ni-base alloys in supercritical water. However, more extensive studies with different water chemistries and strain rates should be made.

Notes

Qualification of structural materials for the advanced 700 C fossil fired power plant – experience gained in the GKM field test loops

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Abstract

Components in 700°C power plants which are subjected to highest temperatures and complex loading situations will be made of Ni-based alloys. Two test rigs with high temperature components (tubes, pipes, pipe bends, headers, valves) have been erected in the GKM Power Plant. Aim of the investigation is the qualification of the component fabrication including welding, the basic design and the study of the life time behaviour considering real loading situations. This covers the evaluation of the damage behaviour also. The results gained will be used to adjust life time assessment and inspection strategies on the specific damage evolution in components made of Ni-based alloys.

The paper describes first results gained. Specific emphasis will be put on the appearance of damage in Alloy 617. The conclusions based on this experience considering design, manufacture and inspection will be reported.

Notes

Creep-fatigue properties of nickel-base superalloy 263

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Abstract

In this paper the creep-fatigue (CF) and low cycle fatigue (LCF) properties of alloy 263 are considered. Both virgin and pre-crept (750ºC / 178 MPa / 3000 h) test materials were tested to investigate the impact of creep damage prior to cycling. The tests performed on the high precision pneumatic loading system (HIPS) are in the temperature range of 700–750ºC, total strain range of 0.6–1.0% and with hold times in both tension and compression. Curves of peak stress as a function of cycles and curves of stress relaxation are presented for the alloy 263. The creep-fatigue test results are also analysed using methods described in the assessment and design codes of RCC-MR, R5 and ASME NH as well as by the recently developed Φ-model. It is shown that the number of cycles to failure for CF data can be accurately predicted by the simple Φ-model. The practicality in using the life fraction rule for presenting the combined damage is discussed and recommendations are given on alternative approaches.

Notes

Fireside corrosion of Ni-based alloys in simulated co-firing combustion environment

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Abstract

Conventional fossil fuel fired power plants contribute significantly to the CO_2 emissions and EU has put in place legislation to reduce its emission to 20% below the 1990 levels by 2020. Co-firing low levels of biomass in conventional power plants has proved to be a successful way to introduce *carbon neutral* fuel into the electricity generation market. In addition, CO_2 emissions from the power plants can be reduced by increasing the operating pressures and temperatures (hence efficiency) of their steam systems. These modifications will require high corrosion resistant Ni-based alloys in the superheaters/reheaters. This paper reports the laboratory-based fireside corrosion tests of three candidate Ni-based alloys (263, 617 & 740). The gaseous combustion environment was designed to simulate co-firing of Cereal Co-Product (CCP) with Daw Mill coal (a UK Midland coal). The tests were carried out using the deposit recoat test method and a synthetic screening deposit (Na_2SO_4:K_2SO_4:Fe_2O_3) was used. The alloys were tested at temperatures of 650–800°C to represent the superheater/ reheater temperatures anticipated in future power plants. The samples were examined by SEM/ EDX to characterize the damage and to quantify the metal damage, pre-exposure micrometre measurements were compared to the post-exposure image analyser measurements on sample cross-sections. In all three alloys, broad front type corrosion attack was observed at 650 and 700ºC without any internal damage. The damage mechanisms in all three alloys changed at the higher two temperatures (750 and 800ºC) and the alloys suffered from significant internal corrosion damage. Alloy 263, 617 and & 740 all suffered from similar median good metal losses at the lower two temperatures (650 and 700ºC); however, at the higher two temperatures (750 and 800ºC) alloy 740 outperformed alloy 263 and alloy 617.

Notes

Degradation of single-crystal gas turbine blades

Petra Jauhiainen, Juhani Rantala, Jorma Salonen, Sanni Yli-Olli & Stefan Holmström

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Abstract

The work presented in this paper aimed to evaluate and classify the microstructural degradation of diffusion coated single-crystal gas turbine blade, so that the characterised features of degradation could be used for assessing the effective in-service material temperatures at the corresponding blade locations.

Two potentially useful indicative measures were evaluated for this purpose: a) gamma prime coarsening and degradation in the substrate microstructure to indicate the condition and temperature in the blade interior and b) combined thickness of the intermediate diffusion zone (IDZ) and topologically close-packed (TCP) precipitate layers to indicate the condition and temperature at the blade coating.

Both applied measures appear to provide meaningful indications of the service temperature, although not with the same level of uncertainty. The thickness of IDZ+TPC layers can indicate the effective temperatures to a relatively good accuracy as long as the IDZ and TPC layers remain sufficiently intact for the assessment. For verification and demonstration purposes, a case example is shown of an ex-service turbine blade.

Notes

Evaluation of creep damage in martensitic 9–10%Cr-steel components

Stefan Zickler & Karl Maile

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Abstract

Martensitic heat resistant 9–12% chromium steels are widely used for the majority of the components subjected to temperatures up to 620°C maximum in coal fired power plants. There have been numerous investigations on the long-term creep strength behaviour by using uniaxial and multiaxial loaded specimens. As a result it was found that with respect to the damage development, the multiaxiality of the stress state has to be considered. Metallographic investigations showed the influence of material, temperature and state of multiaxiality on the formation of creep cavities as a specific feature of martensitic 9–10% Cr-steels. Based on the results gained, it is obvious that the evaluation of damage could not be done on the same basis used for standard low alloy creep resistant steels.

In the paper the differences in damage development will be reported and new approaches for evaluating the creep damage in high-pressure piping and boiler components made of 9%Cr-steels will be shown.

Notes

Influence of boiler operating conditions to component lifetime, case study: pulverized coal burner

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Abstract

In coal fired power plants the most common method of burning coal is in pulverized form. The fuel is fed into the furnace via coal pipelines and burners which are the pipelines last components next to the fireside. The burners main purpose is to optimise the fuel flow for staged combustion. The fireside ends of the burners are exposed to temperatures above 1000ºC and temperature gradients making the burners susceptible to damage through creep-fatigue. In addition to creep-fatigue the fuel flow wears the component surfaces through abrasion and erosion. In general, power plants emphasize operational reliability and therefore material selection and mechanical construction are essential in burner design. Thermal and thermo-mechanical stresses combined with fireside corrosion degrade component lifetimes. This work presents and assesses temperature records from power plants and their influence on component lifetime. The case study component was analyzed by Finite Element modeling. The thermal loads for calculations were defined from temperature records. The results of the analyses show that the primary factor degrading component lifetime are thermal shocks induced from altering boiler operating conditions. The lifetime of the components can be improved by optimizing the material selection and the mechanical construction of the components. As a result of the work suggestions for component material selection and mechanical construction are presented.

Notes

High temperature multiaxial component testing and modelling for the prediction and monitoring of creep-fatigue behaviour

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Abstract

In response to the dynamic electricity market requirements and accommodating the fluctuating availability of energy from renewables, flexible operation of coal fired power plants is required. In addition, maximising operating temperatures is a key requirement to exploit energy efficiency of power plants. For continuous plant operation, creep is a dominant failure mechanism in high temperature components. However for flexible plant operation, which implies fast start-ups, load changes and shutdowns, failure by a complex cyclic stress/strain behaviour can be expected. Therefore, there is a clear need for a deeper understanding of multiaxial high temperature material deformation and damage behaviour in power plant components and validated models are required to predict component failure.

As part of a collaborative European R&D-project denoted MACPLUS, a feature component test of P91 steel is being performed which is being subjected to creep/fatigue conditions by heating and pressurizing the component and simulating shutdown and start-up cycles by employing cooling techniques. A combination of metallurgical material evaluation methods and non-destruct in-service monitoring systems provide valuable tools to assess the condition of plant components and estimate their remaining lifetimes. This paper describes the range of deformation and material damage monitoring tools deployed onto this component and preliminary results from finite element models used to predict the test components elastic-plastic-creep response and damaging behaviour that have been used for the component's design.

Notes

Self-heating and autoignition of coal in rock silos

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Abstract

Storing solid fuels like coal in large quantity is known to involve a risk of spontaneous combustion. In comparison to conventional open stockpiles, closed storage may in principle decrease this risk by more limited ingress of air, but the risk can also be enhanced for example by reduced access for preventive or mitigating action. The risk of self-heating until ignition is considered here for a unique underground rock storage of a coal-fired power plant. The main adverse consequence of non-functioning storage is interrupted district heating that is more difficult to replace in winter than lost electricity supply. To predict the risk of spontaneous combustion with reasonable confidence, material modelling of coal properties has been applied with verification by comparison to actual field evidence. Fire risk management is discussed in terms of the available early warning indicators and options for cooling, extinguishing and prioritised use of stored fuel.

Notes

Creep properties of Zircaloy-4 for nuclear fuel cladding FEA simulation

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Abstract

Zirconium alloys are commonly used as cladding tube material for nuclear water reactors. To improve the understanding of the creep damage accumulation in thin walled fuel cladding tubes made of Zircaloy-4, data collation (tensile, creep strain and rupture) and material modelling has been performed for use in finite element analysis (FEA). In literature there are two distinct areas of creep modelling: creep strain response to short power transients and long term creep strain evolution for storage purposes. In this paper the short term creep strain response is mainly targeted for FEA simulation of fuel-cladding interaction. In addition, the model performance in predicting long term creep strain is verified from the available public domain data. The creep rupture models are optimized for predicting biaxial deformation (hoop strain) of thin walled tubes. The relevant temperature range is selected for postulated system disturbances, i.e. power transients between 300 and 600°C. For the preliminary FEA simulations the material is assumed to be un-irradiated, cold worked and stress relived. The base material models (constitutive equations) do not at this stage incorporate the effect of anisotropy, however two methods of incorporating irradiation effect are presented. The main models applied for this work are the Wilshire equations (WE) for rupture and the logistic creep strain prediction (LCSP) model for strain.

Notes

New applications of pneumatically powered testing equipment for extreme environments

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Abstract

Pneumatically powered loading apparatus designed to allow very accurate and reliable control and measurements of loads and displacements in different environments allow the generation of key mechanical material properties required for the design and life management of nuclear power generation components. This paper describes recent developments and modifications required for new testing applications for challenging environments such as super-critical water, molten lead and hydrogen atmospheres. Also, designs optimized for in-pile material testing are in the conceptual stage. In this paper the basic testing methodology and control systems of the pneumatic loading units are described together with the special features required by the new applications. Test equipment calibration and functionality verification is presented for selected cases together with some unique initial test results. Also, special testing types for future nuclear and hydrogen energy concepts are presented, i.e. liquid metal test loops for lead-cooled fast reactors and test loops for testing in high pressure hydrogen. A set-up for multi-purpose interchangeable specimen types is also presented. The full range of the available testing platforms and environments is briefly reviewed and the future development directions are discussed.

Notes

30 years of nuclear structural integrity – Lessons learned and proposals for future directions

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Abstract

During the past 30 years, many aspects of technical progress have been accomplished. Nevertheless, different issues of degradation have been discovered on different nuclear plant components. This paper will review shortly both technical improvements and major events in order to propose recommendations in term of Gaps and Needs for future projects.

The key words remain: Anticipation, Competences, Safety Culture and Knowledge transfer.

Notes

Forecast reliability of embrittlement trend curves for Swedish nuclear reactor pressure vessel steels

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Abstract

Many nuclear reactor pressure vessels world-wide are ageing, which means that for an approval of lifetime extension, their resistance to failure by brittle crack propagation due to irradiated induced material embrittlement must be assessed. There are two ways to make such an assessment, by material testing of irradiated surveillance specimens and by empirical derived models for embrittlement trend prediction. In Sweden the situation concerning ageing nuclear power plants is the same and therefore an evaluation of already established as well as newly developed embrittlement trend curves (ETCs) is performed. From this evaluation it can be concluded that all evaluated ETCs yield global non-conservative transition temperature shift prediction with respect to base and weld metals. Locally, the embrittlement predictability of base metal is generally superior to weld metal and where four ETC models yield satisfactory base metal prediction. The embrittlement predictability can however be improved by applying a fitness-for-purpose approach using actual surveillance data for ETC modelling. For that purpose one established model is applied and in addition two new models of similar kind have been developed to improve the forecast reliability of the embrittlement trend for Swedish nuclear reactor pressure vessel steels.

Notes

Application of Alloy 690 and associated weld metals in PWRs

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Abstract

The operating experience of major nuclear power plant pressure boundary components has recently shown that Alloy 600 components and dissimilar metal welds (DMW) can markedly affect the plant availability and safety because of increased incidences of environment-assisted cracking (EAC, PWSCC) of Alloy 600 and corresponding weld metals (Alloys 182/82). Alloy 690 and associated weld metals (Alloys 152/52) are widely used for repair and replacement of the affected thick-section components in old PWRs. In new-built reactors they are the major structural materials in a number of components. Weldability of the nickel-base materials is the key issue in manufacturing. In addition to hot cracking in welding, EAC susceptibility is the other major concern of Alloy 690 and associated weld metals of Alloy 152/52 during operation of the PWR plants.

Notes

Performance of copper overpack for repository canisters

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Abstract

The final disposal of the canisters containing spent nuclear fuel involves long term storage in a deep geological repository. The canisters include a 50 mm overpack (top layer) of oxygen free phosphorus doped (OFP) copper for corrosion protection. In storage the canister is subjected to some heating by the residual activity of the contents, requiring reliable prediction of safe creep life from the available rupture and strain properties of the overpack that includes electron beam (EB) or friction stir welds (FSW) for sealing. Assessments of creep strain and rupture at relevant service conditions are inevitably susceptible to any bias in the applied material models, the underlying material data and predictive tools. FSW appears to generally produce stronger welds, although significant creep weakening has been indicated in case of small scale root defects. In EB welds large grains and characteristic patterns of solidification result in some anisotropic mismatch to reduce creep strength and increase strain localisation of welds. In this paper FSW and EB cross weld test results are assessed and compared for creep response. The models have been converted to comply with the requirements for in-house Finite Element Assessment (FEA) code and used for simulating the FSW behaviour. The simulated strain response is compared with corresponding measurements in long term creep testing. The results of the simulations and material models are discussed in the view of targeted life span of the canister overpack. Observations are presented regarding the expected stress, strain and multi-axial constraint in the welded structure.

Notes

The effect of sulphide exposure on the mechanical behaviour of OFP copper

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Abstract

A Japanese research group reported in 2008 susceptibility to stress corrosion cracking of oxygen free phosphorous doped copper (CuOFP) in sulphide containing sea water at T = 80°C and under uniaxial slow dynamical loading conditions. More evidence for stress corrosion cracking has not been found under multiaxial constant loading conditions in sulphide containing groundwater at T = 25°C. Indications of possible sulphur ingress to CuOFP grain boundaries from sulphide containing groundwater were found, which initiated further studies on the possibility of grain boundary embrittlement through such ingress. Further studies were conducted in order to clarify the effect of sulphide exposure on the mechanical behaviour of CuOFP.

Tensile and creep tests were performed with specimens exposed to sulphide and reference specimens. In the studies presented in this paper only small concentrations or no sulphur at all was found on fracture surfaces, in contradiction with earlier studies with precracked compact tension (CT) specimens under constant load. It is suggested that the high concentrations found earlier may have been caused by the method of opening up the fracture surfaces (i.e. post-exposure fatigue in air) and thus be an artefact.

The tensile tests performed after the exposure to sulphide containing groundwater indicate a degrading influence of the exposure on mechanical properties of CuOFP. The result is based on adequate number of specimens and a standard test practise.

The creep tests performed within the studies presented in this paper seem to indicate a minor degrading influence of the exposure to sulphide containing groundwater. However, when compared with all the publicly available creep data on CuOFP from different heats and laboratories the current finding is still within the scatter band.

Notes

NDE of the disposal canisters

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Abstract

The Finnish concept of high activity nuclear waste disposal is based on deep geological storage in copper canisters with cast iron inserts. Disposal canisters will be embedded in Olkiluoto bedrock at the depth of approximately 400 metres. Therefore it is essential to inspect the canisters with non-destructive testing (NDT) methods as well as possible before the final disposal.

The lid of the copper disposal canister for high activity nuclear waste is sealed with a weld. Before accepting the canister to the final disposal the weld will be inspected by four non-destructive testing methods. These methods are ultrasonic testing (UT), radiographic testing (RT), eddy current testing (ET) and remote visual testing (VT) using cameras. The copper overpack and the lid are also inspected with multiple NDT methods; UT, ET and VT. The nodular cast iron insert is inspected with UT and VT.

In this paper the four NDT inspection methods for inspection of different parts of the disposal canister are presented in brief. All information in this paper is collected and summarised from public reports and from the procedures of each method and inspection records. Also experts have been interviewed.

All of the four NDT methods detect defects in slightly different directions and based on different physical principles. The four methods are therefore supplements to each other in inspection of different parts of the disposal canister.

Notes

TÜV NORD concept COOP – A powerful tool to meet the challenges of power plant flexibilization

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Abstract

The energy systems in Europe and the rest of the world are currently undergoing severe changes. Not only due to the growing feeding from fluctuating renewable energies (wind, solar) the energy generation is becoming a highly dynamic system. The number of full-load hours is considerably decreasing and plants are undergoing numerous start-ups and shut-downs with fast load gradients.

The flexible operation regimes probably cause for the components of thermal power units (coal and gas power plants as well as solar power plants and methane production) a paradigm shift in the in-service material degradation mechanism. Particularly for thick-walled components low-cycle fatigue due to faster start-up and shut-down thermal transients gains in relevance versus creep degradation.

To effectively deal with these requirements, the TÜV NORD Group has designed a strategy, COOP (Cycle Optimized Operation), that allows, on the one hand, a reduction of conservative assessments and, on the other hand, the development of new safety standards in the evaluation of the remaining service lifetime.

These conceptual prognosis tools will allow a timely optimization of plant operating modes, a smart NDT inspection concept and finally reduce the life cycle consumption and the maintenance efforts.

Notes

Risk assessment of power station production unit

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Abstract

Risk assessment of the production unit of a fossil power station are based on probabilistic methods in conjuction with application of Bayesian networks. Expected risks are assessed considering available data for failure rates and economic consequences due to outages of key energetic devices of the production unit, and social consequences due to potential injuries. Proposed procedures make it possible to analyse the significance of individual devices and their components with regard to availability of the production unit and human safety.

Notes

Importance of pressure equipment inspection in power plants: Looking to the future

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Abstract

In process industries, equipment failure rates (FR) drive many essential issues in plant management such as inspection programming. Also a few decisions of Competent Authorities, including installation licensing and land use planning (LUP) are driven by FR. A large information entropy, unfortunately, affects Failure rates. FR's currently in use for process equipment derive from systematic studies conducted even in the sixties and seventies. Many new materials and new production method have been introduced and their effects on aging mechanisms on a large scale are almost unknown. Plant Operators and Authorities could make questionable decisions, using poor or generic data. A few European Competent Authorities are trying to face the problem, by stating a set of failure rates, suitable just for LUP. INAIL – Research, Certification and Verification area, as in charge for pressure equipment control throughout Italy, is gathering data for updating general Failure frequencies. This effort is aiming to provide "numbers", on which Authorities and enterprises can count, but above all to pool the knowledge about failure modes in order to better address management of the equipment throughout the process industry. That may improve probabilistic risk assessment and management.

Notes

Investigations of superheater materials from Nordjyllandsværket coal-fired plant after 100.000 hours service

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Abstract

The Danish coal-fired Ultra Super Critical (USC) plant, Nordjyllandsværket, was commissioned in 1998 with 290 bar and 580°C/580°C steam data. The boiler was designed as an USC once-through Benson tower type boiler with double reheat. The challenging steam conditions required the use of state of the art materials, such as P91 or TP347HFG for the construction of the boiler. The plant has now reached 100.000 hours of operation. Taking advantage of the boiler maintenance programme, tube sections were removed from more than 20 different locations in the boiler during the 2012 summer shutdown to assess the materials conditions of the boiler.

The tubes have been investigated to document wall thickness, fireside corrosion and steamside oxidation rates and morphology and microstructure evolution after 100,000 hours exposure. This data together with the temperature data of the plant will serve to give a lifetime evaluation of the boiler components. The present paper focuses on understanding and modelling corrosion and thermal stability of the austenitic alloy TP347HFG that was used as a construction material for superheaters and re-heaters.

Notes

Assessment of remaining lifetime of the boiler tube and microstructure analysis

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Abstract

Assessment of remaining lifetime represents a very complicated problem, which needs the knowledge of degradation processes in the material of a component, and also the service conditions of the components, e.g. way of loading and the influence of the surrounding environment. There is a common interest to operate the produced components as effectively as possible and thus as long as possible without reducing their safety and reliability, what could cause economic and human losses. This is a problem of safe operation and its prolongation in justifiable cases.

As a result of new modern and more resistant materials development, the general interest is to be able to evaluate the extent and rate of degradation processes at various service conditions, mainly to prevent the components from brittle fracture. The goal even in the stage of a component design is to guarantee their long-time operation. At present, the assessment of component material microstructure is one of the methods that makes it possible to evaluate its remaining lifetime.

It is thus important to be able to evaluate the extent of material mechanical properties degradation as a result of various service factors and the elaboration of methods for its assessment.

Nowadays, the evaluation of component material microstructure represents one of the possible methods for remaining lifetime assessment.

Notes

Long term and pilot study of HAZ creep behaviour of weld repaired low alloyed heat resistant steels

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Abstract

In a Värmeforsk project, a plate and waisted HAZ specimen has been developed to examine the creep properties of heat affected zone (HAZ). Comparing to the bar cross weld (CW) specimens taken from weld repairs, the plate and waisted HAZ specimen gives longer rupture time and higher creep ductility. This agrees with the results that all the bar CW specimens fail in the ex-serviced parent metal, meaning that the parent metal is weaker. The creep testing results show also that matched weld repair prolongs creep lifetime for components made of low alloyed steels such as 10 CrMo 9 10, which is frequently used in the power generation industry. Thus, matched weld repair is strongly recommended.

Notes

Corrosion resistance of Kanthal A-1 and Fe-12Cr-2Si alloy coatings in Cl-containing environment

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Abstract

Boiler and tubing materials used in biomass-fired energy production are susceptible to corrosion in severe corrosive environments caused by inorganic constituent such as chlorine at the operating temperatures. In conventional stainless steels, which rely on the formation of a chromia scale for protection against corrosion, the Cl present in the environment reacts with the Cr in the alloy to form volatile $CrCl_2$ and $CrCl_3$ compounds and, thus, reduces the formation of an external, stable chromia scale. The volatile $CrCl_2$ and $CrCl_3$ compounds formed on the surface of the alloy are not able to provide protection against further corrosion and due to the formation of these compounds the conventional stainless steels may lose their resistance to the Cl-containing environment. Alumina and silica forming alloys have been considered as possible solutions against corrosion in these types of applications.

In this study, overlay weld coatings with FeCrAl and FeCrSi type consumables were manufactured on 10CrMo9-10 steel by gas-tungsten arc welding method. Kanthal A-1 with a nominal composition of 5.8 wt. % Al was chosen as an alumina-forming alloy and a silica-forming alloy was Fe-12Cr-2Si alloy with a nominal composition of 2.0 wt. % Si. Performance of the overlay coatings was tested in 168 h potassium chloride (KCl) exposure tests at 600°C in as-welded condition and after 24 h pre-oxidation at 950°C. Composition distributions of the coatings and the formed oxide layers in the KCl exposure were characterized with FEGSEM and EDS.

Notes

A material solution against fireside chloride corrosion

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Abstract

The paper describes the development of a new material solution to protect fireside surfaces against high temperature (500–700°C) chlorine corrosion in severe combustion environments of the energy and process industry. The proposed solution is based on introducing an innovative coating as a surface layer to prevent chlorine and oxygen diffusion into the substrate to be protected.

For experimental verification of the concept, new coatings and hot isostatic pressed materials against chlorine corrosion (Cl-trap coatings) have been exposed to an aggressive chlorine environment at 600°C. The new Cl-trap materials with Ni barriers strongly retarded chlorine corrosion by preventing Cl penetration through lamellar boundaries into the substrate material. The required nearly pure Ni layers were not retained in the HIPed alloys that therefore did not perform equally well.

Notes

Corrosion and carburization of superheater materials in oxyfuel combustion

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Abstract

The energy sector is globally the largest CO_2 emitter. Carbon capture and storage (CCS) is a concept to reduce greenhouse gas emissions resulting from the use of fossil fuels in power generation, and integrated oxyfuel combustion concepts, combustion in oxygen-enriched environment to make post-combustion extraction easier, is studied one of the options for CCS. Oxyfuel combustion can be expected to differ from combustion in air by e.g. modified distribution of fireside temperatures, much reduced NOx but increased levels of fireside CO_2, SO_2 and water levels due to extensive flue gas recirculation. Increased flue gas recirculation may increase the concentration of a number of contaminants in the deposited ash and promote fouling and corrosion. In addition to development of low CO_2 emitting energy generation technologies, improved energy efficiency is essential in order to reach emission reduction targets. Increasing process efficiency requires high in-service temperatures for superheaters and reheaters.

In this paper the corrosion performance of two superheater austenitic steels (TP347HFG and Sanicro 25) has been studied in laboratory tests under simulated oxyfuel conditions with and without a synthetic deposits (85 $CaCO_3$ - 15 wt% $CaSO_4$, $CaSO_4$-0.55 wt% KCl) at 650 and 720°C up to 1000 hours.

Notes

A renaissance in Small Punch testing at Swansea University

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Abstract

For the present work, two specific applications of the Small Punch (SP) test assessment technology were selected, completely different from earlier work in this laboratory. It is shown that the first of these applications takes on board the unique potential of the SP test for testing small quantities of novel or even exotic materials which are candidates for aero engine applications but which cannot easily be produced in quantities which would allow conventional mechanical testing. This has additionally required the development and procurement of new SP test facilities capable of operation up to 1000^0C and above. The examples given in this paper are TiAl intermetallic alloys and niobium silicide alloys studied utilising the Code of Practice for SP Creep Testing (Part A). The second application described in this paper illustrates the use of SP testing to assess the tensile and creep properties of repair welded Inconel 718 alloys. The tensile testing was carried out in a specially designed SP test jig but using the SP Tensile and Fracture Testing (Part B) of the Code of Practice. In all applications, the ranking capabilities of SP testing are proven.

Notes

Practical application of impression creep data to power plant

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Abstract

The measured “minimum” creep rate in the impression creep (IC) test is currently obtained from a “stabilized” deflection rate, and the time to “stabilization” is somewhat arbitrarily chosen at durations up to 500 h, regardless of the applied load. Nevertheless, IC tests have been successfully utilized for aged ½CrMoV and P91 steam line components by conducting tests at the same load so that the deflection rates can directly be compared and used for ranking. By this experience, the IC test is an excellent tool for material ranking and lifing of service exposed material.

However, further development in the IC data assessment procedures and the translation between IC and uniaxial test is still needed for determination of the lower stress range material creep properties from the IC test. It is suggested that the deflection rate should be correlated to a Monkman-Grant type relation with the calculated deflection rate at specified “strain/deflection” against the corresponding uniaxial strain rate at the same specified strain. The modified MG relationship should correct the increasing error expected at IC test conducted at decreasing loads. To be able to do this the strain rate as a function of time (or strain) should be available for primary creep of the uniaxial test. The corrective impact of the modified MG has to be verified by further analysis and testing.

Notes

“On site” X-Ray Diffraction method to observe the creep phenomenon and its propagation at the nano-scale

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Abstract

This paper introduces some elementary concepts to recognise creep occurring in metals and welds, using X-Ray diffraction as a non-destructive method. Understanding creep is complicated by the intrinsic difficulty to observe the on-going process. We introduce here new achievements of X-Ray Diffraction (XRD) as a non-destructive test in its strictest sense, and examples are reported on measurements carried out on a P22 grade steel collector and welded T92 grade steel component.

Progressive dynamic deformation results in plastic effects which affect the crystal rheology, or more generally the lattice rheology; this rheology depends on the associated micro-nano scale structural properties. Moreover, time, temperature and specific loads (pressure) play the conditioning role of grain boundaries size and shape, thus affecting the microstructure, mechanical properties and component integrity. Methods and related technology capable to investigate nano-scale for in-service inspections are currently needed as claimed by several industrial circumstances. In this context, when using XRD, the lattice d-spacing becomes observable with true metrological impact. When welds are considered, d-spacing and microhardness show significant similarities which testify how the dynamic deformation is translated on average from nano to micro scales.

Notes

Differences in defect indications of three artificially produced defects in ultrasonic inspection

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Abstract

Different types of artificial defects are used for qualification of ultrasonic inspection procedures, equipment and personnel for in-service inspections of nuclear components. To reliably evaluate the performance of an inspection, the defects have to be representative enough compared to the real service-induced defects.

Fatigue cracks can nowadays be produced artificially as thermal fatigue or mechanical fatigue cracks. Thermal fatigue crack production is very well controlled in matter of size and opening and those cracks are very realistic option compared to the real service-induced defects. Mechanical fatigue crack production is a well-known and widely used method and can be used to produce very realistic cracks as well.

Ultrasonic indications are highly dependent on defect characteristics like roughness, crack opening, tilt and branching. This work studies the influence of different reflector properties on defect indications. Two different types of artificial defects from different manufactures are inspected with conventional ultrasonic (UT), phased array (PA) and scanning acoustic microscope (SAM) techniques. The aim of the study is to get a wider perspective on the differences in similar type of defects from different manufacturers.

Notes

Detection of magnetite piles on steam generator tubing with eddy current method

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Abstract

The magnetite deposits and deposit piles on the secondary circuit of the steam generator tubing are detected with eddy current method in in-service inspections. The volume of the detected deposit pile is not evaluated. In many cases the growing defects are located at the same area as the magnetite deposit piles. For this reason it is important to locate and to size the piles of magnetite on the steam generator tubing.

In this study experiments were conducted by using eddy current method using bobbin probe techniques and small mock-up simulating the horizontal steam generator tubing. The goal of the experiment was to size the thickness of magnetite piles under and around the test tubes. The results of low frequency tests showed that the thickness of magnetite layer under the steam generator tube can be measured up to 11 mm. The results of the tests showed also that in more general case, where the tube is embedded into unsymmetrical pile, the pile thickness cannot be measured using ordinary single probe technique.

Notes

Model assisted calculations for NDE reliability

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Abstract

There are multiple techniques to assess the reliability of non-destructive evaluation (NDE). Probability of detection (POD) curves can be used to find out the smallest flaw that will be detected with a certain probability and receiver operating characteristic (ROC) curves can be used to determine the performance of the amplitude-based classification systems. However, the problem with these techniques is that they require a large number of measurements for good results.

In this study, ultrasound simulations were used to generate data for POD and ROC analysis. In total 463 cracks with height from 0.5 mm to 10 mm were simulated. Skew and tilt angles of the cracks were normally distributed random variables with deviation of 5°. From height vs. amplitude data, POD and ROC curves were extracted.

Results indicate that due to varying tilt and skew angles, both detectability and classification accuracy decreases due to high variation of the amplitude signal. Moreover, the results show also the capabilities of model assisted probability calculations as a tool to improve NDE methods.

Notes

Experience in integrity assessment of steam turbine casings operated beyond the design lifetime

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Abstract

The basic components of power plants are operated under high temperature and high pressure. Long-term exposure in such conditions causes inevitable degradation of the structure and properties of materials. This paper presents the results of mechanical properties measurements of perlitic steel 15Ch1M1FL exposed at high temperature for different service time. Tensile properties have been measured by testing of miniature specimens fabricated from samples extracted from in-service steam turbine casings. All the tests have been performed at room temperature with metal structure investigation.

Notes

Evaluation of mechanical properties and microstructure of dissimilar weld joint of COST F and FB2 steels after long term creep test

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Abstract

Trial dissimilar weld joint was prepared from COST F and COST FB2 type steels using TIG HOT-WIRE method in conditions used in industrial praxis for production welded steam turbine rotor. Long-term creep tests to the rupture of smooth cross-weld samples have been carried out at temperatures ranging from 550 to 650°C and at stresses from 70 to 220 MPa. Fractographic analysis, hardness profile measurement and study of submicrostructure using light, scanning and transmission electron microscopy have been performed. Creep strength of weld joint falls into ±20% scatter band of the creep strength of the base material COST F up to 600°C. Different types of cracking were observed in dependency on conditions of creep test: fractures were located in the base material of steel COST F at lower temperatures and higher stresses and in the fine prior austenite grained or intercritically reheated part of heat affected zone of steel COST F where cavitation failure was evident.

Notes

Determination and solution of power plant furnace problems with pilot-scale studies

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Abstract

VTT has three pilot-scale combustors in Jyväskylä: a 20 kW reactor to simulate bubbling bed combustion, a 50 kW reactor to simulate circulating fluidised bed combustion and a 100 kW reactor to simulate grate combustion. Good scaling up of results to power plant level is based on realistic temperature vs. residence time history in the furnace, realistic ways to bring combustion air in at several stages and inert wall materials (due to high wall area to inner volume ratio compared to power plant furnaces). However, reactors alone would be insufficient to research. In addition, versatile sampling and analysis systems are necessary. VTT has unique probes to gas analysers and to devised for aerosolic fly ash and condensed vapour. These are important to find out and solve corrosion relative problems in power plants. VTT has participated to product development and combustion problem solution work with numerous companies, in EU funded and domestic network projects with these reactors.

Notes

New model for steam oxidation of power plant steels

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Abstract

At high temperatures the water/steam side oxidation resistance is an important issue for boiler components like superheaters, where the growing internal oxide decreases heat transfer and increases surface temperature. This is increasingly critical for modern plants that aim for high efficiency from elevated levels of operating temperature and pressure. In this paper, a new simple model is presented to describe the steam/water side oxidation rate of common alloys for the high temperature end of the boiler plant. The model is based on the chemical composition of the alloys, applying equivalence expressions for collapsing the multi-variable problem to a more easily manageable setting with a combined parametric oxidation (POX) model. For verification, a range of experimental water/steam oxidation data from numerous tested alloys has been compared with the model predicted oxide growth. The results suggest a surprisingly good agreement with the model and test data. Although the optimised model parameters differ between e.g. steels and nickel alloys, as expected due to difference in the oxides, they remain very similar within a given material class, e.g. for all tested steels.

Notes

Coating solutions against high temperature corrosion – performance validation and feasibility at biomass fired boilers

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Abstract

To overcome severe corrosion problems of heat exchanger surfaces, especially superheaters, in biomass fired boilers protective thermal spray coatings can be applied. Fouling and corrosion in biomass boilers originate from used fuels, which contain alkali metals, chlorine and other corrosive elements, and can lead to tube failure and leakage in the worst case. Different HVOF (high velocity oxy-fuel) and arc sprayed coatings were exposed to biomass co-combustion conditions in a CFB boiler using peat, coal, SRF and biomass as fuel.

VTT is conducting a programme of material exposure trials at the Alholmens Kraft power plant in the city of Pietarsaari. The exposure campaign involves the deployment of one corrosion probe in a 550 MW_{th} circulating fluidised bed boiler. Duration of the measurement campaign was about 1300 hours. The corrosion probe measurement was performed for samples with five coatings: NiCr, IN625, Diamalloy 4006, SHS9172 and NiCrTi. Samples were exposed at two metal temperature ranges of 550 and 750°C, which correspond to both todays and future steam temperatures of a high-efficiency boiler. Used reference tube materials were ferritic steel T92 and nickel super alloy A263.

Performance validation of the coatings was performed as well as an indicative analysis of the effects of fuels, deposit properties and boiler process parameters on corrosion phenomena. Preliminary economic feasibility of the use of coatings to extend lifetime of a superheater was included. Overall at 550°C the coatings had negligible corrosion and at the higher temperature clear differences emerged: NiCr and NiCrTi being the top performers.

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Life in plant – challenges and solutions

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Abstract

Power plant structures operating at high temperatures are designed for a lengthy explicit or implied minimum life, dictated by the expected life-consuming damage mechanisms like corrosion, creep, fatigue and other forms of wear and tear. The actually realised damage shows highest rates at locations of the most adverse combination of material properties (weakness e.g. in welds), loads (mechanical, environmental, thermal) and other features like geometry and deviations from the intended condition. In case of no additional surprises, the technically justified life is likely to nevertheless differ from the assumptions in design. The explicit or implied "safety factors" will offer on average some extended life and service potential to components even after operation up to and beyond the nominal design life. To avoid surprises, it remains wise be well informed of the evolving material and component condition of an ageing plant. The common questions are when and how should one measure to achieve the required confidence for decisions to run, repair or replace.

In this paper we contemplate the challenges for managing the life of critical components of current and future power plants. Radical changes may happen in the merit order of plants by e.g. shifting fuel prices or public policies, and this could naturally affect the need, available budget and planning to maintain a given plant. Less impact is expected in the established principles of the technical operations like monitoring, inspections and interpretation of the results. However, changes are likely in selected areas related to materials and component lifing.

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