CO-ORDINATION OF EUROPEAN RESEARCH IN STRUCTURAL MATERIALS FOR POWER GENERATION EQUIPMENT

Christof Sommitsch[a], Rod Vanstone[b], Torsten-Ulf Kern[c], Peter Barnard[d], Peter Mayr[e], Rachel Thomson[f], Alina Agüero[g]

[a]Institute for Materials Science and Welding, Graz University of Technology, Kopernikusgasse 24, 8010 Graz, Austria, christof.sommitsch@tugraz.at
[b]Alstom Power, Newbold Road, Rugby, CV21 2NH, UK, rod.vanstone@power.alstom.com
[c]Siemens AG, Energy Sector, Rheinstr. 100, 45478 Muelheim an der Ruhr, Germany, torsten-ulf.kern@siemens.com
[d]Doosan Babcock, Birmingham New Road, Tipton, West Midlands, DY4 8YY, UK, peter.barnard@doosan.com
[e]Institut für Füge- und Montagetechnik, Technische Universität Chemnitz, Reichenhainer Strasse 70, 09126 Chemnitz, Germany, peter.mayr@mb.tu-chemnitz.de
[f]School of Aeronautical, Automotive, Chemical and Materials Engineering, Department of Materials, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK, R.C.Thomson@lboro.ac.uk
[g] Área de Materiales Metálicos, INTA, Ctra. de Ajalvir Km 4, 28850 Torrejón de Ardoz, Spain, agueroba@inta.es

Abstract

Over the last 25-30 years, the main focus for development of improved steels for power generation equipment (boilers, steam turbines, pipework systems) has been the concerted actions of COST 501, 522 and 536. These actions have been very successful. Steels were developed and have been applied to critical components such as boiler tubing, pipework and turbine castings and rotor forgings. These enabled an increase in steam parameters from 540-565ºC to 600-620ºC, bringing benefits in reduced fuel costs and lower emissions.

A new framework for co-ordination of this effort was launched in 2012. KMM-VIN (Knowledge-based Multi-functional Materials Virtual Institute), is a legal entity established in 2007 with membership of mainly academic institutes. In 2012 it experienced significant expansion as around 40 participants, including many industrial companies from the power generation industry and its supply chain, with long history of working together within the COST Actions, joined the organisation. An Energy Materials Working Group (WG2) has been formed and has adopted a work programme for the further improvement of steels for power generation plant. One of the main goals for this work programme EMEP (Engineered Micro- and nanostructures for Enhanced long-term high-temperature materials Performance) is the industrial-scale demonstration of components using the advanced MARBN steel concept, steels with potential to allow increase of operating temperatures from 600-620ºC to 650ºC. The authors of this paper are leading work topics within this work programme.

In the same way that the COST Concerted Actions provided a framework for collaboration between projects funded by many different agencies, WG2 has already fostered collaboration between projects funded by the European Commission Framework Programme, e.g MACPLUS and POEMA, projects funded by national governments, e.g the UK IMPACT project, projects funded by academic funding agencies, e.g EPSRC, and projects funded privately by WG2 industrial partners.

Keywords: Steam power plant, efficiency improvement, alloy design, microstructure modelling and process simulation, ferritic-martensitic steels, steam oxidation, coatings

1 Background

1.1 General background

Clean coal power is one of the most challenging technologies in the light of ongoing discussions on climate change versus the security of a steady affordable electricity supply to the fast growing world population. Coal power supplies 40% of world electricity and is growing fast in highly populated areas such as China and India because of its high energy density per commissioned unit compared to the renewable energy types available today. Efficiency increase of coal fired steam power plants is an indispensable technology step towards clean coal power since it is economical, it enables enormous direct reductions of CO_2 emissions and it compensates part of the efficiency loss from carbon capture and storage (CCS) technologies.

The efficiency of steam power plants is limited by the availability of new stronger high-temperature materials with improved temperature capability, which allows the construction of plants operating at increased steam pressure and temperature. Extended long-term integrity of steam power plant components for 30 years of reliable operation at high temperature requires both resistance to microstructure degradation and to oxidation in steam as well as for boiler parts at fireside. Currently developed steels allow steam parameter up to 300bar and 600-620°C.

Targeted material development will enable further reductions of emissions and improved planned economy. Improved steels for 325bar and 650°C will permit an increase of efficiency of affordable steel based steam power plants from today's maximum of 46% up to a value close to 50%, equivalent to 8% reduction of specific CO_2 emissions.

The present Working Program aims to achieve such a steel development in an open networking between European partners across the whole power plant materials sector, including universities, research institutes, manufacturers of steel components, power plant manufacturers and power plant operators. The defragmentation of universities and industry know-how enabling the advance of competitiveness relative to other economic areas in the world is a key factor to maintain Europe's standard of living in future.

The unique cross-sector network of KMM-VIN WG2 Materials for Energy is highly effective both for directing university research towards "hot topics" and for fast implementation of results by industrial partners (both large and small).

This great advantage by using the KMM-VIN WG2 Materials for Energy open networking approach cannot be realized in other research frameworks such as ESF, ESA, EUREKAS or the EU Framework program. During the running program, further partners can join without any obstacles and introduce their knowledge to widen the expertise range and achieve the challenging goal of network development.

1.2 Current state of knowledge

Because of their combination of high creep and fatigue strength, toughness, oxidation resistance and moderate costs the ferritic-martensitic steels are potential materials for operation in fossil power plants with increased steam parameters.

The European material development includes steels for thick section boiler parts, piping and turbine components, which are key components in the steam power plant, where better material is needed in order to advance the steam parameters. Long-term laboratory testing of the new materials has been carried out up to 100,000h after screening tests of a larger number of testing melts. Specimens from pilot components (rotors, valve bodies, thin and thick walled parts) tested in different ways have confirmed the transferability of properties from 50-500kg melts to full size 30t parts. The application of the newly developed steels in 23 new steam power plants with advanced steam parameters up to 275bar/600-620°C, built by European steam plant manufacturers demonstrates the success of such a development path for new steels.

Microstructure investigations (XRD, LM, SEM, FIB, TEM, EFTEM, 3D APFIM, etc.) of specimens of virgin condition and after long-term creep testing of base material and welds identified precipitation strengthening as the key mechanism to stabilize the tempered martensitic structure against creep. Microstructure and creep modelling based on thermodynamic equilibrium and multi-component diffusion modelling using software such as Thermocalc, DICTRA, and MatCalc, have supported the understanding of microstructure - property relationships of this class of steels. However, the definition of new alloy compositions has not significantly advanced beyond a trial-and-error approach.

Over the past three decades, the development of new ferritic-martensitic 9Cr steels with improved creep strength led by Europe and Japan has enabled advances in steam conditions from subcritical 180bar/540°C to supercritical 300bar/600-620°C corresponding to about 30% reduction in specific CO_2 emissions. Long-term oxidation tests up to 300bar/650°C in steam environment in laboratory as well as field tests in a steam plant up to 57,000h have demonstrated that steels with 9%Cr do not have sufficient oxidation resistance for a steam temperature of 650°C. Such steels will need surface coatings at temperatures higher than 600-620°C. Steam oxidation of a number of coatings (Al slurries, thermal spraying, CVD siliconizing and nickel plating) has demonstrated the feasibility of coatings to improve the oxidation resistance.

Oxidation and creep tests of steels modified from 12%Cr steels have demonstrated that such a Cr content provide sufficient oxidation resistance for steam temperatures up to 650°C at least under atmospheric pressure. However, all attempts to develop 12% Cr steels with sufficient creep strength for 325bar/650°C steam condition have failed due to microstructure instabilities leading to a breakdown of long-term strength. It is now evident that the breakdown is caused by the increase of the Cr content from 9 to 12%, which is found to accelerate the transformation of fine vanadium and niobium based nitrides into coarse Z-phase nitrides (Cr(V,Nb,)N) resulting in a severe loss of precipitation strengthening. Moreover, recent oxidation testing carried out under supercritical steam conditions at 650º C indicates lack of sufficient oxidation resistance.

Similar development projects were run by individual companies in Japan and led to many steel compositions with high Cr and Co contents. This resulted in unstable microstructures in the long-term range, caused by the formation of Z-phase at the expense of MX-nitrides. In addition, a government funded 15-year research project was carried-out in Japan at the National Institute for Materials Science (NIMS) aiming at the development of stronger ferritic-martensitic heat resistant steels. A well balanced composition of boron and nitrogen in the steel led to the strongest available steel i.e., a 9%Cr-3%W-3%Co-VNbBN ferritic-martensitic alloy, which seems to have the potential for 630-640°C application from creep strength point of view. It will, however, still require surface coating against steam oxidation. The mechanism for the strong effect of boron to improve creep strength is still not fully understood. Some modern power plants with steam parameters of up to 280bar/605°C based on newly developed 9%Cr steels are in service or under construction in Japan. There is a strong interest and growing research activities in the development of new high temperature steels of the present class in the Asian economies Korea and China as well in India.

The present Research Program is addressing the development of improved steels and coatings in an innovative way. Recent advantages in micro-nanostructure characterizations techniques (Cs-corrected High Resolution TEM, 3D Atom Probe analysis 3D electron tomography and FIB targeted sample preparation) and novel modelling tools (improved kinetic and microstructure and atomistic modelling, together with improved process modelling) which are available at network partner institutes and universities are used in combination with the manufacturing and testing capabilities available at industrial partners. This unique network facilitates a streamlined development of innovative steels and coatings based on advances in the understanding and predictability of relationships between their micro/nanostructure and properties. This approach is termed “Engineered Micro- and nanostructures for Enhanced long-term high temperature materials Performance – EMEP”.

1.3 Reasons for the Working Program

The realization of improvements of the properties of heat resistant 9-12%Cr steels requires extensive knowledge, experience and equipment of participating universities, institutes and manufacturers of steels, components, boilers and turbines as well as power plant operators which will be merged by the cross sectional network of the experts of these organizations.

The planned added value of this KMM-VIN WG2 Materials for Energy network is a reduction of the CO_2 emission of around 8% by the increase of the steam parameters of the nowadays level of 275bar/600°C to 325bar/650°C of coal-fired steam power plants at limited investment costs. Continued use of coal will also improve the security and affordable steady electricity supply due to widespread low-cost, long lasting (150+ years) global coal reserves. It is estimated that replacement of old inefficient power plants and implementation of state-of-the-art technology in all new-built plants could lead to annual global savings up of to 1.7 Gigatons CO_2, equivalent to 5.5% of the global emissions (IEA 2008).

This KMM-VIN WG2 Materials for Energy network is aimed at European economic/societal needs as well as at scientific /technological advances of Europe. The results of this development will ensure worldwide competitiveness and maintain a high employment rate in European countries such as steel and metal plants, producers of large forgings, foundries, boiler makers, and turbine manufacturers. Finally, the defragmentation of university and

industry know-how and experience will promote the economic and scientific position of Europe.

1.4 Complementarity with other research programmes

The need to decrease CO_2 emissions has initiated further activities in research and development in Europe.

In Germany, the national COORETEC program (CO_2 REduction TEChnologies) is run to support the development and improvement of energy supply technologies with the focus on CO_2 reduction. In the UK, there is a running project IMPACT to further strengthen the steel research for the energy and power plant industry. The application of steels for coal fired, nuclear power, or natural gas fired power plants is regarded as a prerequisite to be able to develop economic solutions for the future. European projects, such as CRESTA, AUSPLUS, Z-ULTRA, NextGenPower, POEMA and MACPLUS dealt or are also dealing with the development of high temperature materials.

KMM-VIN is already a platform of interaction with these research projects to ensure that new technical developments and research work is integrated in the working topics of EMEP.

2 Objectives and Benefits

2.1 Aim

The aim of EMEP is to enhance process efficiency and reduce greenhouse gas (particularly CO_2) emissions in thermal power generation by developing innovative ferritic-martensitic steel grades and their coatings that facilitate operation at steam temperatures of 650°C or higher; and to verify the required temperature capability of the new steels to serve as critical components, in particular headers, steam lines and turbines.

2.2 Objectives

The targeted improvement in the process efficiency is 20%, in comparison with the current average efficiency level in Europe and the rest of the world (maximum steam temperatures of 580-610°C in new plant), with a corresponding reduction of CO_2 and other emissions. The solutions for use with steam temperatures up to 650°C will be realized using a novel approach which considers the mechanisms influencing the steel below the grain scale and the impact on the macroscopic structure. This Research Program exhibits broad alloying concepts, developing these through modelling of the micro/nanostructure development during processing leading to the prediction of the properties of interest. In addition to suitable mechanical and fabrication properties, the ability to survive in aggressive environments, such as high-pressure steam, is also critically important. EMEP aims to develop radically new methods of surface engineering through microstructure and coating routes to protect the alloys. The candidate alloys and surface solutions are validated first through testing in small-scale batches and then demonstration for large-scale components. Key objectives to meet are:

- Identification of innovative alloying concepts, promising steel compositions and surface engineering solutions for elevated temperature service
- Identification of coating systems capable of withstanding long term steam oxidation

resistance at 650º C
- Evaluation of most promising surface engineering solutions
- Production of small scale melts (<100kg), to be selected for satisfactory properties in fabrication (welding, casting, forming, heat treatment, non-destructive inspection, coating, etc.) and improved performance under service conditions (mechanical and environmental resistance)
- Characterisation of material (coatings and materials) microstructures down to a nanoscale. Tailoring materials micro/nanostructure for desired properties. Optimisation of the processing route, if necessary.
- Production of the best alloys and protective solutions in the scale of prototype components (approx. 10 tons)
- Development and qualification of welding consumables and joining strategies for new alloys
- Testing and verification of the new materials systems in terms of the life-limiting long-term performance (creep, fatigue, oxidation, etc.) towards acceptance for new plant design.

In recent years, the steel and power generation industries have suffered from a perception that they are in decline and unadventurous, dirty and lacklustre. Consequently, there have been noticeable difficulties in attracting fresh graduates with the inevitable result that there is now both an ageing workforce and a gender imbalance within the industry. To address this, EMEP has a set of secondary objectives, which are:
- to attract fresh bright graduates in the research on challenging new materials for future power generation
- to improve the image of the steel and power generation industries highlighting the challenges and rewards from careers in these industries
- to promote the competitive research, micro/nanostructure characterisation- and modelling methods and expertise for materials development activities within the scientific partnership network including the collaborating universities and research institutes
- to develop solutions withstanding higher temperatures than any earlier alternatives which advance competiveness of European companies providing materials, components, equipment, design and systems.

2.3 How networking within EMEP yields the objectives

KMM-VIN WG2 Materials for Energy comprises a network of research institutes, the material supply chain, OEM´s and generators from across Europe. The combined expertise and scientific facilities within the network encompass all the required know-how and technologies required to achieve the prime objective, including material characterization, modelling, processing and testing. Each activity within EMEP comprises an optimum mix of these groups that will enable precise delivery of the objectives without losing focus or becoming unwieldy.

The network also exposes, thorough collaborative activities, interactions, workshops and meetings, early stage researchers at universities to industrial companies and encourage them to consider future careers in the power generation industry after achieving their qualifications.

2.4 Potential impact of EMEP

A key component within the range of measures to reduce CO_2 and other emissions is to increase the efficiency of fossil fuelled power stations. This has both an intrinsic benefit and also enables the economic introduction of carbon capture technology into the plants. As a direct benefit the steels developed within EMEP will enable the construction of high efficiency plants with operational flexibility and with reduced costs compared to the introduction of Ni-base alloys. These new power plants will produce environmental benefits and energy security in Europe.

Indirect benefits of the Research Program will be an increase in industrial competitiveness in Europe through the knowledge generated and the strengthening of the R&D capability. An additional benefit will come through the stimulation of early stage and female researchers and an increased interest in the industries involved in EMEP.

2.5 Target groups/end users

The output from EMEP is used through the entire supply chain including material producers (steelmakers), material fabricators (e.g. forgemasters), coating companies, OEMs and end users (power generating companies). Involvement in this Research Program benefits universities and research institutes, extending their knowledge and expertise through building links with industrial companies, facilitating future collaboration and scientific innovation. Both stakeholders and end users were strongly involved in the preparation of the proposal.

3 Objectives and Benefits

3.1 Scientific focus

The degradation of long-term creep strength and oxidation resistance accelerates with increasing temperature and thereby limits the temperature capability and lifetime of components fabricated from ferritic-martensitic steels.

Creep degradation of the ferritic-martensitic steels is controlled by the stability of the tempered martensite microstructure against the plastic deformation at high temperature. High microstructure stability is mainly obtained by precipitation strengthening from numerous micro- or nano-sized hard particles of carbides, nitrides or intermetallic phases, which nucleate and grow in the microstructure mainly during the final quality heat treatment of the steels. During service loading, the precipitate particles coarsen, and their strengthening effect is gradually lost. Furthermore, new precipitates can nucleate and grow during service exposure or existing precipitates can dissolve or transform into other precipitate types. Control of the precipitate particles to form a distribution of numerous fine particles, which remain stable (fine) during long-term exposure to high temperature will enable increased creep strength of these steels. It is estimated, that the temperature at which the 100,000 hour creep rupture strength is 100MPa will limit the temperature capability of a given steel.

Steam oxidation of the ferritic-martensitic steels results in the formation of metal-oxide layers on components exposed to hot steam. If the oxide formation rate becomes too high it might result in spallation of oxide layers from the exposed surfaces, which could lead to blockings

and erosion damage in steam cycle components. The Cr content in the steels primarily controls the oxidation rate of the martensitic 9-12%Cr steels. It has been found that a Cr content of 9% will result in oxidation rates, which limit the temperature capability of the steels to 600-620°C. Further, in laboratory atmospheric pressure steam oxidation testing it has been found that, a Cr content of 12% or higher is needed to obtain oxidation rates, which will increase the temperature capability up to 650°C. However, in recent high-pressure tests, also carried out in the laboratory under supercritical conditions, higher Cr alloys such as VM12 (12 wt% in Cr) or even austenic steels such as 316LN (16.8 wt% in Cr) do not exhibit the required oxidation resistance. In fact, little is known about the effects of pressure in the stability of protective oxide scale.

3.1.1 Strength enhancements

The previous developments of new martensitic steels capable of temperatures up to 600°C were mainly based on the optimization of minor alloying contents of vanadium, niobium and nitrogen, which resulted in precipitation of finely dispersed (V,Nb)N nitrides along with $Cr_{23}C_6$ carbides. Further improvements were targeted by additions of tungsten, leading to the formation of Fe_2W intermetallic Laves phase and the addition of 20-150ppm of boron, which increases the long-term creep strength of the steels. The underlying mechanism of boron strengthening is still unknown, and will be targeted in this Research Program. Special emphasis will be put on an optimum balance of the boron and nitrogen contents in the steels. This development has high potential to meet the requirements for strength enhancement and to increase the temperature capability of ferritic-martensitic steels up to 650°C. However, the lack of understanding of the strengthening mechanism by boron currently only leads to new developments based on a trial-and-error approach. By contrast, the different strengthening mechanisms and influencing parameters, supported by modelling activities, will be studied in detail here.

So far, it has not been possible to obtain sufficient creep strength at 650°C of 12%Cr steels simply by (V,Nb)N nitrides or boron. Still, more stable coarse Cr(V,Nb)N Z-phase particles form with time in expense of finely distributed (V,Nb)N and result in a loss of precipitation strengthening and a breakdown of the long-term creep strength. An increased Cr content, necessary for improved oxidation resistance, accelerates this formation of Z-phase nitrides. One approach is to use the more stable Z-phase itself as a strengthening phase and promote a finely dispersed precipitation of Z-phase. Other strengthening phases like intermetallic phases or yttrium dispersoids in ODS alloys will be investigated. Based on different strengthening mechanisms and computer simulations, new steels with improved creep strength will be developed.

3.1.2 Surface engineering

Radically new methods of surface engineering are required to modify the surfaces of candidate structural materials such that their oxidation properties are improved with no deficit to the strength. Surfaces can be ‘engineered’ in a number of ways, but in general the methods fall into two categories, namely microstructure and coatings.

Microstructure modification can be achieved in a number of ways, through heat treatment, mechanical treatment, alloying etc. Better understanding and control of the effect of microstructure modification is needed. EMEP aims to conduct fundamental investigations on the oxidation resistance and oxidation mechanisms of different ferritic-martensitic steels after

selected surface treatments have been performed. This will include the microanalysis of the internal stresses present in the surface layers as a function of the depth, investigation of the microstructure at the surface and in the near surface area (by cross-sectional SEM and FIB-TEM) as well as the surface topography (by AFM) as this will affect the diffusion paths and consequently the oxidation rate. In parallel a thorough metallographic investigation will be carried out on 9%Cr steels that showed unexpectedly high steam oxidation resistance at 650ºC in order to understand the causes. In addition treatments such as shot peening are known to improve oxidation resistance, however, the processes must be made more reliable and reproducible. Clarification of the microstructure mechanisms of corrosion and the means to curb the oxidation mechanism will also be investigated. In addition the effect of higher temperatures, non-isothermal and thermal transient conditions will be a subject for fundamental, mechanistic and laboratory development. EMEP will support modelling activities and will contribute to validate any produced models.

Whilst microstructure control and surface modification (such as peening) would be the preferred method for increasing the range of applicability of conventional alloys, the use of coatings is a promising option for providing oxidation and corrosion control for alloys which lack the oxidation resistance whilst having sufficient mechanical properties. New coating systems will be applied based on multi-step processes, if required including depositions techniques such as electroless, hot-dipping, thermal spray, slurry application anodic oxidation, etc. Understanding the degradation of coatings, application method and tailoring the coating composition and microstructure is vital to the success of coating technology. The Research Program will focus on these aspects and has consequently identified key areas of interest that will be addressed. These include basic research on the microstructure stability of the coating in supercritical steam and fireside environments, the effect of the coating on the mechanical properties of the alloy as well as the optimization of already developed coatings and the development of new ones. Figure 1 shows the steam oxidation behavior at 650ºC of an aluminide coating developed during the previous COST action. The coating protects P92 and has already reached more than 70,000 h of exposure without signs of substrate attack. Moreover, not only the typical Al and Cr based coatings, but also the behaviour of intermetallics and alloys formed with the substrate and other elements will be explored. Care will be taken when selecting coatings and coatings processes so that non-toxic or environmentally unfriendly species are formed. Other aspects include surface preparation prior to application of the coating, optimization of the diffusion treatment (temperature and time steps) when required and developing models to predict the performance of the coating in service. Components, which are likely to need coatings, will be defined and the most adequate coating deposition method will be selected for each specific component. Finally, a very important issue that will be addressed is the definition of new steam oxidation testing parameters that better reflect real operation conditions. Most laboratories have been testing under atmospheric flowing steam or steam/Ar mixtures isothermally, but recent results have shown that the laboratory observed spallation behaviour of uncoated substrates is significantly different from that in a steam turbine at 150 bar. Moreover, access to high-pressure laboratory rigs will establish the presently not fully understood effect of pressure on oxide scales, Cr, Si and Al based. Finally, the synergy between steam oxidation, wear and/or erosion of coatings and new materials will be studied specifically for valve seats.

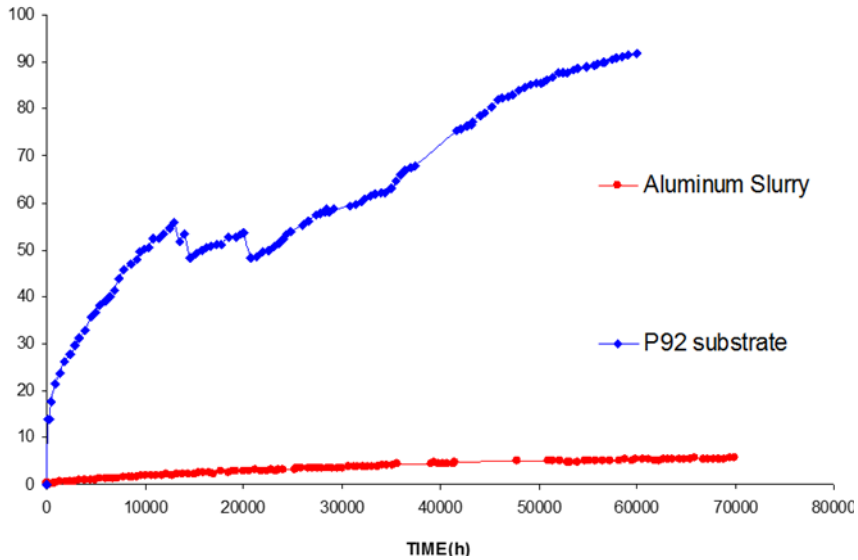


Figure 1: Mass change of a slurry aluminide coating deposited on P92 when exposed to flowing steam at 650º C in the laboratory.

3.1.3 Microstructure characterization and modelling

For both strength enhancements and surface engineering the strategy for improvement of temperature capability of this group of materials is to focus on replacing the trial-and-error approaches with engineered micro- and nanostructures for optimum performance by science-based modelling approaches, i.e. to optimize compositions, heat treatment schedules or manufacturing techniques in order to stabilize microstructures over an extended period of time. This is based on improved understanding of mechanisms of the essential degradation processes of creep and steam oxidation by detailed characterization and modelling of microstructure evolution.

Microstructure characterization methods have advanced significantly in recent years. In addition to well-known metallographic techniques, advanced high-resolution and analytical transmission electron microscopy (EFTEM, EDS with SDD detectors, precession electron diffraction, Cs corrected STEM/HAADF and HRTEM, 3D electron tomography) as well as Focused Ion Beam (FIB) sampling are now available at many partner institutes. This allows unprecedented details of crystal defects or local chemistry of precipitate particles to be revealed on a sub-nano scale. The latest generation 3D atom probe equipment provides much faster analysis on the atomic scale, which can widen the range of this powerful characterization technique. Atom probe in combination with localized sampling by FIB is the most useful technique to locate boron in the microstructure, and thus help to clarify the mechanism of ppm additions of this element to strongly enhance creep strength. Recently, a new possibility for unambiguous characterization of three-dimensional shape and real size distribution of the strengthening precipitates is given by electron tomography (EFTEM, HAADF and FIB tomography). Experience has shown that it is essential to investigate laboratory samples exposed for very long times (5-10 years) in order to draw the right conclusions. Industrial partners in EMEP will share such unique samples.

Microstructure stability and creep modelling are absolutely necessary to evaluate the combined influence of up to 10 alloying elements on microstructure stability in order to optimize chemical compositions and heat treatment schedules. Thermodynamic equilibrium

and multi-component diffusion modelling using software such as Thermocalc, MatCalc and DICTRA has advanced significantly. This will be used to evaluate influences of chemical composition on precipitate phase formations and interdiffusion between coatings and substrate, as well as effects of shot peening on oxidation rates. Novel software such as MatCalc can evaluate influence of composition and heat treatment on the rate of nucleation, growth and coarsening processes for precipitates. Generated microstructure data will be used to validate the modelling as well as to refine underlying thermodynamic and kinetic databases to include critical phases such as e.g. boron containing precipitates. Figure 2 shows an example of a thermodynamic equilibrium calculation for a MarBN steel.

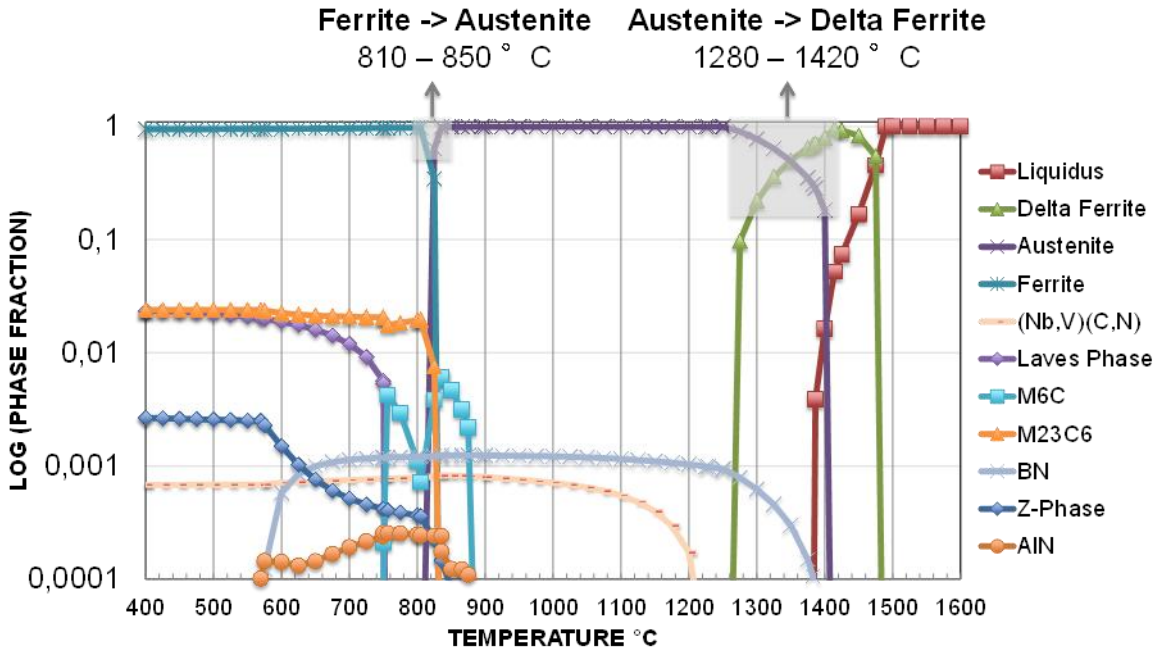


Figure 2: Thermodynamic equilibrium calculations of a MarBN steel using the software MatCalc.

Ab-initio modelling can also generate basic thermodynamic and kinetic data as enthalpy of formation for precipitates and atomic jump ratios in specific crystal systems. Neural network approaches will provide a broader view of influential factors, which might otherwise not be recognized.

3.1.4 Manufacture and validation of trial materials and components

Steelmakers, forgemasters and foundries will manufacture trial melts of 50-100kg size with optimised compositions and heat treatment resulting from the microstructure characterization and modelling exercises. Mechanical and oxidation testing including long-term tests will be made at partner laboratories in order to validate the properties of the developed materials.

Welding of pipes and other components is known to lead to a loss in creep strength of the heat affected zone (HAZ), which has an adverse effect on components lifetime in power plants. New welding consumables will be developed and tested along with the materials solutions for base materials. Recent results indicate that in 9%Cr steels an appropriate balance of boron and nitrogen could suppress the strength loss of the weld HAZ in an innovative way. This will be thoroughly tested in the Working Program by manufacture and testing of welded joints. Figure 3 shows a macrograph of a MARBN crossweld creep tested at 650°C and 70MPa (a)

and corresponding hardness map (b). Simulation of the lifetime of welded components under creep loading based on finite element methods will be carried out.

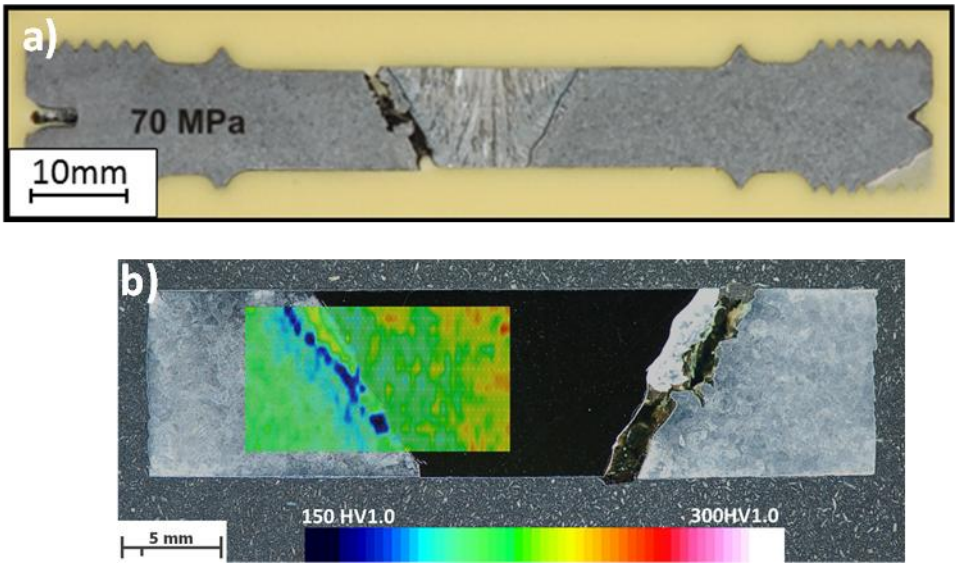


Figure 3: a) Cross-section of a MARBN crossweld sample tested at a stress level of 70MPa at 650°C and b) corresponding hardeness map including weld metal, damaged area in the HAZ and base metal.

Manufacture of large components weighing up to 30t by casting or forging may produce microstructures, which deviate from the ideal laboratory case. E.g. segregation and non-ideal precipitate distributions may lead to reduced creep strength, or grain structures in the centre of large forgings may reduce the possibility for ultrasonic inspections. This seems to be of particular interest for boron alloyed steels. EMEP will implement simulation tools to optimize manufacturing processes in order to minimize such deviations. Forgemasters and foundries will supply components for validation of simulation tools to predict effects of solidification and forging processes on segregation and residual stresses in large components, forging of trial samples are shown in Figure 4.



Figure 4: Forging of MarBN Trial Billets.

Industrial partners will manufacture full-size demonstration components of steam pipes, cast valves and full size trial rotors from successful trial melt compositions. Figure 5 shows MarBN tubes for insertion in power plant for long term testing. These components will be thoroughly tested to validate their properties for plant application prior to installiation in commercial operating plant.



Figure 5: MarBN Tubes samples ready for insertion in power plant for long term testing.



Figure 6: MarBN cast bonnet manufactured by Goodwin Steel Castings Ltd within the UK IMPACT project. The reason of a sectioning a 30° cross sectional slice out from the bonnet was to conduct mechanical testing.

An example of the collaboration fostered within the KMM-VIN/EMEP framework is the development of MARBN castings. A casting (Figure 6) was manufactured by Goodwin Steel Castings Ltd. within the IMPACT project part funded by the UK government. The casting was 3.5tonne to pour (around 1.75tonne after method removal) and was part of a 9tonne AOD refined melt. Short term testing within IMPACT has indicated a 25-30 degree C increase in temperature capability compared with current state-of-the-art high temperature casting steels

but longer term testing is necessary to confirm this potential. Samples from the casting are therefore being distributed to other partners in KMM-VIN who have offered to carry out the required long term testing. Further scale-up of this casting technology is planned within a UK funded project starting in April 2014 and it is again anticipated that longer term testing will be conducted within KMM-VIN/EMEP.

4 Economic Dimension

The benefit for the European industry after successful performance of the project will be given by availability of cost effective material solutions for different power plant applications covering all activities for high temperature power plants and Carbon Capture and Storage (CCS) technologies.
The benefit for European science is predicted to be a new kind of networking, a continuous transfer of knowledge to young researchers, and stronger interaction of academia and industry to enable a faster transformation of new solutions into practice. This will strengthen the international importance of European research community.

5 Summary

Despite the indisputable results in implementing new environmentally friendly energy production technologies and fuels, the coal will remain the major fuel source for global electricity production. Unfortunately, coal combustion leads to relatively high CO2 emissions per kWh, which is a highly imminent and challenging task for the mitigation of climate changes. Employing Carbon Capture and Storage together with increased net efficiency in all newly built power plants will lead to meet the EC 20-20-20 target. However, new stronger high temperature steels and coatings for boilers, steam lines and turbines, are required.
This Research Program will develop innovative materials solutions based on detailed understanding and modelling of high-temperature microstructure degradation processes and surface protection against steam oxidation, and on simulation of manufacturing processes for large components to ensure optimal properties during scale up from laboratory samples to industrial use.
KMM-VIN / WG2-EMEP is conducted by a unique network representing universities, research institutes, steel producers power plant component manufacturers and power plant operators. This will enable defragmentation of European research efforts, interdisciplinary education of early stage researchers both from science and industry, and lay solid foundations upon which Europe can build future networks and maintain its leading position in this highly competitive field.

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