KME PROJECT STATUS REPORTS, 2/2016

KME
CONSORTIUM MATERIALS TECHNOLOGY
for thermal energy processes

Date
2016-09-29

Reporting period: January 2016 – June 2016

Status report KME

Project title: Influence of high-temperature environments on the mechanical behaviours of high-temperature austenitic stainless steels

Project no: KME-701 (EM 39297-1)

Project manager: Mattias Calmunger

PhD:s/lic:s: (working in the project and degree of activity)

Hugo Wärner (Lic., 100%) started as a PhD-student 2016-07-01.

Project goals:

The main purposes of this project are to evaluate the mechanical behaviours for structure safety and integrity analysis, namely:

1. To evaluate the creep and LCF interaction diagram and integrity analysis since the boiler materials can undertake both creep and low cycle fatigue during the service.
2. To evaluate the structure stability and the toughness after long term service at an elevated temperature for safety analysis.
3. To evaluate thermo-mechanical fatigue properties of the boiler materials for safety and life evaluation since the power plants can start/shutdown quite often during service for energy saving and flexibility purposes in the future.
4. To evaluate the stress relaxation cracking behaviour of the boiler material. It is critical problem for some boiler materials.

Progress in relation to project goals:

Project tasks 1.1 is in progress relating to the main purpose and the first goal by performing and later evaluating specified tests, where the testing is completed. In relation to the second goal the ageing is finished, the mechanical testing of CTOD is ongoing. Some analysis has been started

according to the time schedule for task 2. Task 3.2 is in progress in accordance to the project time schedule and is related to the third goal. The mechanical testing is planned to be finished in September. Hugo Wärner was employed as a M.Sc.-thesis worker 2016-02-02 within the KME-701 project and started as a PhD-student 2016-07-01 which contributing to the overall goal of training technical doctors and licentiates within the program.

Summary over results and work so far (max 1/2 A4-page):

Thermo-mechanical fatigue (TMF) testing of aged materials has been performed in strain control using a temperature range of 100-800 °C both in-phase (IP) and out of phase (OP) and a dwell time of 5 min in tension. The TMF life of virgin and aged materials are shown in figure 1. The virgin materials show a greater TMF-life than the aged materials for the same mechanical strain ranges. The aged specimens had problems with buckling which is the reason why lower mechanical strain ranges have been used as well. Generally, the stress range of the aged materials increases during the TMF test leading to a reduced number of cycles to failure compared with the virgin materials that show a decreasing stress range during the TMF test. Due to buckling most OP tests were stopped at 500 cycles to be able to perform microstructural analysis later. Only Sanicro 31HT (labeled "OP cycle – aged") is shown in OP in figure 1, OP shows a greater TMF-life than in IP for the aged material. All materials will be examined using microstructural analysis, trying to explain the reduced TMF-life of aged materials.

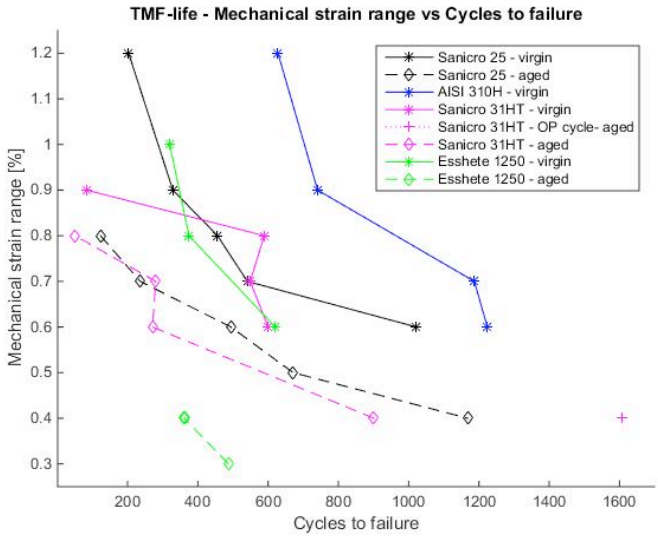

Figure 1: TMF-life for virgin and aged materials (AISI 310H is only in virgin condition) represented by the mechanical strain range and the number of cycles to failure. All materials except Sanicro 31HT – OP cycle – aged are represented in IP.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

The costs are according to the plan and no deviations to report. The schedule is mainly according to the plan, deviations on Task 1.1 otherwise no deviations to report. The deviations are related to broken test equipment's but this will not affect the project from deliver according to the project goals.

Number project reference group meetings held until report date:

A reference group meeting was held 18th of May 2015 in Linköping and a second reference group meeting was held at Swerea KIMAB the 20th of April 2016 with all project participants represented. Next reference group meeting is planned to the end of the spring 2017.

Planned activities:

The microstructural evaluation of the TMF tested specimens (task 3.2) is planned to start during the autumn. Toughness tests after long-term ageing (task 2.1) and evaluation (task 2.2), evaluation of creep/LCF interaction tests by establish the diagram of creep and LCF interaction (task 1.1) and stress relaxation cracking method development (task 4-1) are also planned to be performed.

Date
2016-10-06

Reporting period: January 2016 – June 2016

Status report KME

Project title: LCF and TMF crack growth in cast nickel-based superalloys

Project no: KME-702 (EM project no 39279-1)

Project manager: Johan Moverare

PhD:s/lic:s: (working in the project and degree of activity)

Christian Busse (80%), Frans Palmert (50%)

Project goals:

The aim of the project is to validate materials for future industrial gas turbines where there is a strong need for high fuel flexibility, availability and efficiency, as well as cyclic operation. This will require materials with high corrosion resistance and good resistance to TMF crack growth.

The key objectives of the project are:

1. Validate a TMF crack growth test method that can be used to generate high quality data for cast nickel-based superalloys, including single crystals.

2. Generate high quality test data for TMF crack growth in conventionally cast IN792 and the single crystal superalloy STAL15.

3. Improve the knowledge regarding the mechanisms that controls the crack growth rate for conventionally cast superalloys as well as for single crystal superalloys (e.g. influence of crystal orientation, phase shift and temperature-strain history).

4. Develop TMF crack growth models and life prediction methodologies that will reduce the need high safety margins. Today the safety of single crystal crack growth is in the order of three decades. The idea is to bring this order of magnitude down by one decade.

5. Validate the models for component near conditions.

Progress in relation to project goals:

- The isothermal testing to support goal (1) to (3) has continued. Test data is now available for 20°C and 500°C. Testing at 750°C is ongoing.
- Stress controlled thermo-mechanical fatigue (TMF) crack propagation testing to support goal (1) to (3) are ongoing. IP and OP TMF between 100-750°C have been considered so far. Both STAL15 and IN792 are under investigation.
- Microstructure investigations to support goal (3) have started.
- Modelling related activities to support goal (4) and (5) is ongoing.

Summary over results and work so far (max 1/2 A4-page):

Since last status report isothermal crack propagation testing has been performed by LiU at 750°C using a miniature size DCT-specimens. Tests with different load levels and also blocks with different lengths of the dwell time during the tests has been performed. Further testing has been performed by Siemens using Kb-type specimens. Some of the results are shown in Fig. 1.

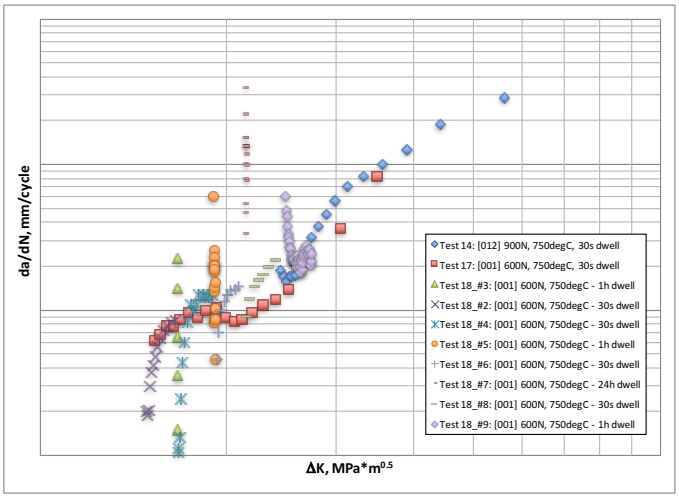

Fig 1: *Crack propagation rates in STAL15 at*

Regarding the modelling part of the project; A fracture mechanics tool is developed, which enables the possibility to calculates anisotropic Stress Intensity Factors resolved on a crystallographic slip plane in a three-dimensional context. This methodology makes it possible to analyze complex finite element-models, which are more application-near than traditional two-dimensional models. It is investigated which crystallographic slip plane experiences the highest stresses and is therefore most likely to show crystallographic cracking. When comparing to the experiments, the developed resolved shear stress intensity factor parameter is able to predict the correct slip plane on which crystallographic occurred for all evaluated tests on KB specimens. Further experiments on a DCT specimen will be used to validate the methodology.

The idea is to use the developed parameter to find a criterion which indicates a change of cracking mode (from a crack perpendicular to the load direction to crystallographic cracking). It will be investigated if this methodology is also applicable as a crack driving force parameter during crystallographic cracking or if it has to be modified.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

Schedule and costs according to plans. No deviations

Number project reference group meetings held until report date:

Five project group meetings and one reference group meeting. The reference group has also been updated of the progress of the project via telephone and e-mail.

Planned activities: (3-4 lines)

- Continued isothermal fatigue crack growth testing at 750°C.
- Continued TMF crack propagation testing.
- Tension/Compression tests for constitutive modelling.
- Simulation of the DCT-tests in single crystal material.
- Continued investigations of the crack appearance and the deformation and damage behaviour

Date
2016-04-04

Reporting period: Jan 2016 – June 2016

Status report KME

Project title: Durable MCrAlX Coatings for demanding applications in gasturbines

Project no: KME-703 (EM project no 39296-1)

Project manager: Ru Peng

PhD:s/lic:s: (working in the project and degree of activity)

Till 2015-02 PhD Kang Yuan 100%

From 2015-05 PhD student Pimin Zhang 80%

Project goals:

The main aims of the project are:

1. To develop new durable MCrAlX coatings with improved performance for applications in medium size industrial gas turbines operating on a flexible base in terms of fuel and operation mode
2. To contribute to increased understanding of correlations between chemical composition, coating process, microstructure and performance of MCrAlX coatings
3. To study the influence of applications of MCrAlX coatings on the behavior of superalloys.

Progress in relation to project goals:
Tasks 1-2 and 4-7 related to goals 1 and 2 are going as planned. Composition refinement by simulation for all proposed coating systems are complete. Characterization of TCF resistance is done and that of oxidation resistance is almost complete for two Ni-base and one Co-base coating systems. Corrosion test is to be start very soon.

Tasks 3 directly related to goal 3 is ongoing. DBTT and TMF have started.

Summary over results and work so far (max 1/2 A4-page):

Further refinement of chemical composition by simulation on the Ni-base and Co-base coating systems from phase 1 of the project is complete. TCF and all isothermal oxidation on the Ni-base are complete except for the 10000h test. The positive effect of Ru on resistance to interdiffusion and negative effect of Ce on surface oxidation were shown. For the co-base system, TCF test and isothermal tests for up to 5000 h exposure time are complete. The refined Co-base systems did not show improvement in the oxidation behaviour, which could be related to the addition of Hf to some coatings and a poor control of the coating composition and thickness by the sample supplier. Further post-test analysis is underway and new trials with samples from a new sample supplier is under consideration. A conference paper is published and a journal paper is under review.

Composition optimization by simulation was done for two new coating systems, one with three phases for enhanced mechanical properties and the other, a Ni-base with Fe addition for cost reduction. TCF and isothermal oxidation tests on the Fe-containing coating systems are complete except for the 10000h test. The results revealed that the addition of Fe within the studied range does not seem to impose negative effect on the oxidation and TCF resistance.

DBTT and TMF tests have started.

The condition for the formation of a beta-layer at the substrate-coating interface was analysed by simulation on a number of coating-substrate systems. The results were published in a conference and a journal paper. Extensive simulations to reduce the potential negative or to enhance the possible positive effect of interdiffusion on oxidation behaviour are ongoing. New experiments to confirm the simulations are under discussion.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

Corrosion test to be done by an external research institute is expected to start soon. Otherwise, time schedule and costs follow the project plan and budget.

Number project reference group meetings held until report date:

1 reference group meeting. A second one is planned for the autumn 2016.

Planned activities: (3-4 lines)

1. Post-testing analysis of the isothermal aged and TCF tested Co-base coatings
2. Continuing isothermal aging
3. Continuing DBTT and TMF test of coated specimens
4. Test to evaluate the performance of selected coatings as bondcoat in TBC
5. Corrosion test on the Ni- and Co-base coatings in an external lab
6. Further work with oxidation-diffusion modelling

Date
2016-09-30

Reporting period: 2016 03 31 – 2016 09 30

Status report KME

Project title: Project title: $MoSi_2$ matrix composites for combustion components exposed to high temperature oxidation and hot corrosion

Project no: KME-705

Project manager: Yiming Yao

PhD:s/lic:s: No.

Project goals:

To produce $MoSi_2$ based composites having high temperature corrosion resistance for furnace and gas-turbine combustion chamber components aiming at operation temperatures ≥1200°C.

Progress in relation to project goals:

- Final sintering at 1700°C in air was performed on pressure-less sintered $MoSi_2$-SiC composites, aiming at improving sintered density and HT oxidation property.
- XRD analysis was conducted on as-sintered and 1700°C sag-tested $MoSi_2$-SiC and (Mo,Al)Si_2-SiC materials.
- Hardness and Kc tests as well as microstructure characterization were performed on $MoSi_2$-SiC and (Mo,Al)Si_2-SiC composites.
- Isothermal oxidation at 1400°C is being performed on the final sintered $MoSi_2$-ZrO_2 and $MoSi_2$-SiC composites.
- The article "Property and Oxidation Behaviors of (Mo, Cr)Si_2+ZrO_2 composite Produced by Pressure-Less Sintering" was published in Journal of Materials Science and Chemical Engineering, **4** (7) 2016, 15-21.

Summary over results and work so far (max 1/2 A4-page):

- Non-productive oxidization occurred in $MoSi_2$-SiC composites during final sintering at 1700°C in air, due to internal oxidation of SiC particles that led to formation of CO_2 gas. It is indicated that the oxidation test and final sintering treatment for the SiC reinforced composites should be performed below 1700°C.
- SiC additives play a positive role in protecting the sintered surface from the reduction in sintering gases. There was no formation of silicon depleted Mo_5Si_3 silicides in the as-sintered regions in both $MoSi_2$-SiC and (Mo,Al)Si_2-SiC composites.
- Dispersion of SiC additives strongly affects material properties. Large amounts of big pores (with diameter of several hundred μm) in $MoSi_2$-SiC, and hard SiC agglomerates in (Mo,Al)Si_2-SiC were observed, which results in low sintered density of $MoSi_2$-SiC and low strength of (Mo,Al)Si_2-SiC.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

The time and cost schedule follows the project budget plan.

Number project reference group meetings held until report date:

A project reference group will be held in November when the isothermal oxidation test is finished.

Planned activities: (3-4 lines)

- Isothermal oxidation tests will be finished in November.
- Extensive ball-milling and, if necessary, adding suitable dispersants will be performed before X-mas 2017, in order to improve SiC dispersion.
- Sagging test at 1500-1600°C will be carried out right after the new materials with improved dispersion are produced.
- Characterizations will follow the relevant preparations and tests.
- A manuscript for the final sintered $MoSi_2$-ZrO_2 composite will be prepared.

Date
2016-09-29

Reporting period: January-June 2016

Status report KME

Project title: Weldability of nickel-base superalloys for energy applications

Project no: KME-706 (EM project no 39283-1)

Project manager: Lars Nyborg (+46 31 772 12 57, lars.nyborg@chalmers.se)

PhD:s/lic:s: A PhD student (Fabian Hanning) is working in the project.

Project goals:

The continuation project aims to investigate and clarify the fundamental cause of formation of weld cracking, or more specifically strain age cracking. As basis for this overall aim, the goal is also to establish a test procedure for the assessment of the susceptibility towards strain age cracking of precipitation hardening Ni-based alloys.

Progress in relation to project goals:

The project proceed according to project the goals.

Summary over results and work so far (max 1/2 A4-page):

So far, focus has hence been laid on establishing background knowledge and on defining the path of research. This has been achieved by an extensive literature review, resulting in a conference paper at the Swedish Production Symposium. Important factors for strain age cracking (SAC) have been identified and included in the experimental planning for simulative tests. Furthermore, PhD courses with a total of 18 credit points (27 until end of year) have been completed, providing knowledge in welding of superalloys and materials testing. Together with 7.5 credit points obtained in Q4 2015 more than half of the required PhD courses will be completed within this year. As this already meets the requirement for the licentiate examination, more emphasis can now be laid on experimental research.
An extensive material analysis within the scope of a repair welding study has been carried out, of which results have been presented at the IIW annual meeting in

comission IX-H. By representing actual welding conditions, the study yields information on material performance under conditions close to reality. These results are to be complemented by simulative tests, providing more detailed insight into the ongoing mechanisms. After finalizing additional microstructure evaluation the study will be ready for publication. Submission to a scientific journal is intended for Q4 of 2016.
In view of the installation of a Gleeble thermomechanical simulator at University West in Trollhättan early in Q4, it is aimed to carry out simulative tests on different nickel based superalloys for a closer investigation of strain age cracking. This is planned to be a larger scale investigation, continuing into 2017.
Until end of 2016, 3 conferences will have been attended, including the presentation of parts of the research. These are the IIW annual conference, held in Melbourne, Australia; the Swedish Production Symposium (SPS) held in Lund and the Swedish Aerospace Conference 2016 in Stockholm. While the presentation at SPS includes the submission of a full paper, the other conferences do not count as a publication. A total of 2 published articles is anticipated during this year, based on the conference paper (SPS) and the planned submission of the repair welding study to a scientific journal. In addition, beam time at APS in Chicago have been a granted and tests will be carried out in the first week of November 2016 as well as in 2017.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

The budget is according to plan both at the university and slightly ahead at the industry.

Number project reference group meetings held until report date:

Seven meetings have been held at GKN so far and external reference meetings will take place during the autumn.

Planned activities: (3-4 lines)

1. Continue analyses on the repair welded Haynes 282 samples
2. Continue to analyse the Gleeble tested samples that were carried out at UoM
3. Continue to carry out analyses on the tests carried out at the Advanced Photon Source and carry out additional experiments
4. Put up a new testing rationale at the Gleeble testing machine at University West/Chalmers University of Technology

Date
2016-08-19

Reporting period:

Status report KME

Project title: IMPROVED STEAM TURBINE DESIGN FOR OPTIMUM EFFICIECNY AND REDUCED COST OF OWNERSHIP

Project no: KME-707

Project manager: Magnus Genrup , Marcus Thern

PhD:s/lic:s: Srikanth Deshpande (100%)

Project goals: The aim of the project is to improve the turbine efficiency for increased production capacity and associate revenues – for potentially a reduced cost of ownership.

The increased turbine efficiency / performance will contribute to the overall ambitious KME efficiency target

Progress in relation to project goals: As per project plan – Report D6 will be issued by end of August 2016

Summary over results and work so far (max 1/2 A4-page): Pursuing the efforts towards improving the efficiency of tall stages, airfoil improvements and pitch to chord ratio alterations were considered. Flow path modifications were also attempted. Two publications were written with the work carried out in order to report the performance improvements by these avenues.

Stator and Rotor airfoils were redesigned. Stator airfoil was designed to be relatively aft-loaded. Transition from laminar to turbulent boundary layer was delayed by changing the curvature on the suction side of the airfoil. Profile losses were reduced and efficiency improvement of 0.1% was achieved. Rotor airfoil was made relatively front loaded. The deflection of flow at the leading edge of the rotor airfoil increased the Mach number to the levels from which the exit Mach number could be reached without further acceleration. The reaction of the stage being very low (around 0.15), the acceleration at the

leading edge of the rotor airfoil was sufficient. Also, the inlet metal angle was corrected in order to reduce the incidence losses. Overall, rotor airfoil improvement resulted in 0.27% efficiency improvement.

Flow path modification was attempted next. The presence of axi-symmetric endwall contour (Russian kink) on the flow path was evaluated. Conclusion from this study was that, the endwall contour assists in reducing the tip leakage losses. Though the endwall contour is historically used for short stages, its presence in tall stages helps to reduce the local pressure and hence affect the flow behaviour in the tip cavity region.

In order to examine the effects of change in pitch to chord ratio in stator, the number of stator blades was reduced from 60 to 50. By reducing the number of blades, blade loading per airfoil section was increased since the pressure drop across the blade row was retained from the baseline configuration. However, due to reduced wet area, the efficiency increased by 0.15%. To further increase the pitch to chord ratio, the chord of stator airfoil was decreased by 3 mm. The performance of the stage increased further by 0.1 %.

Similar modifications were attempted on the rotor airfoil. The chord was reduced by 2 mm. Overall improvement of the stage due to airfoil modifications and increased pitch to chord ratio in efficiency improvement was 0.74%. Simultaneously, the cost was also reduced on material and manufacturing of 10 stator blades. However, compliance of the modifications to the strength and mechanical requirements is to be established. This part of the work is outside the scope of the project definition.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

Planned activities: (3-4 lines)

Commence the design modification and trials on the short stages. The performance of the baseline configuration is completed.

To evaluate the short stage performance from 1D, 2D and 3D perspectives.

Optimise the airfoil design in order to minimise the profile losses.

Evaluate the 3DV and 3DS designs for the short stage stator and rotor blades.

Reduced part count with increased stage efficiency

Currently spending four months at ITB in (Mumbai India) testing turbine cascades in a rig.

List of Publications :

1. Efficiency Improvements in an Industrial steam turbine stage – Part II

   Proceedings of ASME Turbo Expo 2016: Turbine Technical Conference and Exposition, GT2016, June 13 – 17, 2016, Seoul, South Korea

2. Efficiency Improvements in an Industrial steam turbine stage – Part I

   Proceedings of ASME Turbo Expo 2016: Turbine Technical Conference and Exposition, GT2016, June 13 – 17, 2016, Seoul, South Korea

3. Influence of Compound Lean on an Industrial Steam Turbine stage

   Proceedings of ASME Gas Turbine India Conference 2015: GTINDIA2015, December 2 – 3, 2015, Hyderabad, India

4. Vortexing Methods To Reduce Secondary Losses In A Low-Reaction Industrial Turbine Vane

   Proceedings of ASME Turbo Expo 2015: Turbine Technical Conference and Exposition, GT2015, June 15 – 19, 2015, Montréal, Canada

5. Reduction in secondary losses in turbine cascade using contoured boundary layer fence

   Proceedings of ASME Gas Turbine India Conference 2014: GTINDIA2014, December 15 – 17, 2014, New Delhi, India

Date: January 2016- June 2016

Status report KME-708 (EM 39270-1)

Project title: High temperature corrosion in used-wood fired boilers. Part 1

Project no: KME-708 (EM 39270-1)

Project manager: Pamela Henderson

PhD:s/lic:s: (working in the project and degree of activity)
For 2015 - Yousef Alipour 100%, Annika Talus 10%
For 2016 Annika Talus 40%

Project goals: To reduce high temperature corrosion, in a cost-effective way, in heat and power boilers that burn mainly used (recycled) wood. Most effort is directed towards furnace wall materials. This can be achieved by:-

(1) Finding coating materials that are more cost-effective than Ni-base alloys (e.g. cheaper or more corrosion resistant). The goal is to reach a 20% reduction in cost or corrosion rate.
(2) Obtaining a better understanding of the connection between fuel quality (fuel chemistry) corrosion rate
(3) From the results of short-term testing with digested sewage sludge decide whether to proceed with long-term testing of sludge as an additive, i.e decide whether to run part 2 (KME 718)

Progress in relation to project goals:

Goal (1) is 85% complete. Testing to support the goal is complete. Economic evaluation remains.

Goal (2) is 80% complete. Long-term testing in a power plant and short-term testing in the laboratory have been completed, but some detailed microscopy remains.

Goal (3) has been fulfilled. Digested sewage sludge showed benefits under 15h tests. Application for Part 2 (KME 718 - to run longer term tests and measure corrosion rate) was made and project started February 2016.

Summary over results and work so far (max 1/2 A4-page):

Corrosion testing with probes on a variety of different alloys has been performed by the industrial partners Vattenfall, E.ON and Foster Wheeler. Both superheater and furnace wall tests have been performed in boilers firing used wood. Low alloy steels showed very high corrosion rates. Stainless steels, FeCrAl alloys and Ni-based alloys showed good corrosion resistance.

Full scale fuel quality testing was performed in Nyköping with two different used wood compositions (low Cl-low Pb and high Cl- high Pb), but still within used wood specifications. The high Cl-high Pb batch resulted in a greatly increased corrosion rate. In the high Cl-high Pb case lead-rich compounds were found close to the metal substrate, the iron chloride layer formed in 16M03 was thicker and more Ni,Cr and Mo had leached into the deposit from the Ni-base alloy.

Short-term laboratory-scale testing in SP's FB rig with the same batches of fuel from Nyköping has been completed and specimens sent to KIMAB for analysis.

Sandvik Heating Technology has developed welding procedures for cladding furnace tubes with the FeCrAl alloy APMT. A test tube has been coated with a variety of materials (including APMT) and was made ready for installation in Uniper's (formerly E.ON's) used wood fired boiler, Blackburn Meadows, UK.

Since the beginning of the project five scientific papers have been written by KTH, KIMAB and Vattenfall for journals. Four have been accepted or accepted and published. One doctoral thesis has been written

Yousef Alipour (KTH) obtained his Ph.D on 27th November.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations: Both time schedule and costs are according to plan.

Number project reference group meetings held until report date:

Two project group meetings in 2014. One combined reference group and project meeting at the Nyköping power plant on 25 August 2015. One combined reference group and project meeting at Energiforsk on 7th June 2016.

Planned activities: (3-4 lines) Planned activities for July - December 2016.

Installation of coated wall tube in Blackburn Meadows (The tube will remain in the furnace for at least a year and be evaluated in KME 718).

Microscopy on the specimens with High Cl , low Cl fuel from laboratory testing. Comparison of full-scale and laboratory exposure.

Delivery of final results from all project partners.

Writing and delivery of final report to Energimyndigheten

Date
2016-09-30

Reporting period:

Status report KME

Project title: Increased steam temperature in grate fired boilers - Steamboost

Project no: KME-709

Project manager: Torbjörn Jonsson, Chalmers

PhD:s/lic:s: T. Jonsson (25%), J. Phother (30%), L. Paz, J (40%). Liske (5%), *K. Hellström (5%) (until 2016-02-01), N. Israelsson (10%) (until 2015-07-01)*

Project goals:

- Higher steam parameters & high electrical efficiency
- Development of novel solutions where steam is superheated in the furnace
- Develop improved material solutions – including alumina formers

Progress in relation to project goals:

The Steamboost material installed in the boiler was removed and analysed. A part of the un-cooled FeCrAl tube was in addition cut and analysed. All of the exposed materials have now been analysed regarding material loss and selected materials more in detail with IC and SEM/EDX. Probe exposures (initial corrosion/deposit test) has been performed for a large number of boiler settings. All the deposits have been analysed and a preferred setting have been selected. Short/long time corrosion tests have been performed and some of the samples analysed.

The laboratory studies are running as planned. We have received a large number of model alloys that are being exposed in parallel to commercial

alloys. One of the model alloys have in addition been exposed during the probe test in the boiler. A new method of depositing KCl have been developed together with the HTC project 1a.

The half way report was submitted where the work has been summarized and a strategy for the second part of the project have been elaborated based on the results.

Summary over results and work so far (max 1/2 A4-page):

The aim with the first stage of the project was to generate knowledge about:

• CFD calculations - deposit formation.

• The corrosion behaviour of the different materials (stainless steels and FeCrAl alloys) at the different temperatures – focus on corrosion mechanisms.

• The corrosion properties of FeCrAl material by a tube consisting of FeCrAl inside the furnace near the Steamboost.

• The need for a ceramic shield.

The first part of the project has been successful and a large number of samples have been generated both through the extensive field exposures and laboratory work. The main results acquired so far have been compiled in order to determine the direction for the second stage of the project.

The laboratory studies have been focused on pre-oxidization and we have now also started to investigate different amount of alkali salt at 600 °C. Two presetations/papers have been submitted/shown on "Impacts of Fuel Quality on Power Production" conferens, held 19-23 September 2016 in Prague.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations: Yes, however some companies are slightly behind with in-kind reporting.

Number project reference group meetings held until report date:

We held a reference group meeting (2015-22/10). The next meeting is planned to be held at chalmers during december.

Planned activities: (3-4 lines)

Based on the results obtained within the first stage of the project a detailed plan has been elaborated for the second stage of the project. However, more analysis is needed and will be conducted on the large set of samples generated in the first stage of the project.

The field exposures performed within the commercial waste-to-energy boiler AffaldPlus will focus on long time exposures of a new set of fixed installed material without a ceramic shield. The FeCrAl tube will be exposed (samples cut and analysed in detail) in order to get samples after three exposure times during the project period. The laboratory work will focus on model alloys provided by Sandvik Heating Technology in KCl rich environments. We are in

addition discussing the possibility to performe complementary probe exposures of new model alloys in the waste-to-energy boiler AffaldPlus.

Date
2016-09-30

Reporting period: 2016-04-01–2016-09-30

Status report KME-710

Project title: Design of a new generation of 12 % chromium steel

Project no: KME-710 (EM project no 39286-1)

Project manager: Assistant Prof. Fang Liu (Deputy Manager 2014-11-01–2015-05-31 was Prof. Hans-Olof Andrén)

PhD:s/lic:s: (PhD student Masoud Rashidi, 90%. Licentiate seminar 30th September, 2015)

Project goals:

1. Based on the results obtained from the previous KME project and the parallel EU project, design three new test steels with fine-tuned chemical composition, aiming for improved creep resistance compared to the ones that have been designed and investigated in the previous KME 510 project;
2. Optimize heat treatment conditions for test steels;
3. Perform mechanical and creep testing on promising test steels with optimized heat treatment;
4. Understand the sophisticated effects of carbon addition on the precipitation reaction sequences in the Z-phase strengthened steels;
5. Understand effects of small addition of B on the Z-phase strengthened steels;
6. Understand special effects of Ta in combination with Nb;
7. Understand evolution of microstructure and its influence on the creep mechanisms.

Progress in relation to project goals:

We have finished most of the planned work from last report. However, XRD was not prioritized any more, since we have obtained some results using synchrotron radiation on similar materials. Goals 1 and 2 are fulfilled with the

production and heat treatment of the series ZU 1-3. Regarding goal 3, creep testing on ZU1, ZU2 and ZU3 has all been started after last report. A Master's thesis work was performed on test alloys ZU2 and ZU3. Some interesting new results have been obtained addressing particularly goal 6.

Summary over results and work so far (max 1/2 A4-page):
We have continued the work with characterizing the microstructure of 3 newly melted trial steels, ZU1, ZU2 and ZU3. (The chemical composition of these trial steels is provided in Table 1 in Appendix.)

1. For goal 6: We found that: 1) Carbonitrides with a lower C/N ratio transform faster to Z-phase after tempering, i.e. with relatively high Cr concentration. 2) The Nb/Ta ratio are higher in Z-phase particles compared to MX carbonitrides. Further experimental investigations are in progress. We also have collaboration with theoreticians, who will carry out DFT calculations. The joint effort will provide a deep understanding on the effect of C on transformation from MX to Z-phase.
2. For goal 7: Microstructure evolution of Laves phase formed in ZU2 and ZU3 has been studied. We found that the amount of Laves phase is higher in steel ZU3 compared to ZU2, since steel ZU3 contains more Laves phase forming elements (0.56 at% W + 0.3 at% Mo) compared to steel ZU2 (0.64 at% W). (This was part of the Master's thesis project for Robert Lawitzki, Jan-Jun 2016).

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

We follow cost and time schedule plans.

Number project reference group meetings held until report date:

Seven project meetings:

1. At Chalmers, August 28, 2014; present Lennart Johanson, Siemens; John Hald, DTU; and Masoud Rashidi, Fang Liu and Hans-Olof Andrén, Chalmers.
2. At Siemens, Finspång, December 4, 2014; present Lennart Johanson, Torsten Kern and Arne Karlsson, Siemens; John Hald, DTU; and Masoud Rashidi and Hans-Olof Andrén, Chalmers.
3. At DTU, April 9, 2015; present Lennart Johanson and Torsten Kern, Siemens; John Hald and Frank Niessen, DTU; and Masoud Rashidi and Hans-Olof Andrén, Chalmers.
4. At Chalmers, September 3, 2015; present Lennart Johanson and Torsten Kern Siemens; John Hald, Irina Fedorova and Chitta Ranjan Das, DTU; and Masoud Rashidi, Fang Liu and Hans-Olof Andrén, Chalmers.

5. At Siemens, Finspång, December 17, 2015; present Lennart Johanson, Torsten Kern, Siemens; John Hald, Irina Fedorova, and Chitta Ranjan Das, DTU; and Masoud Rashidi, Hans-Olof Andrén, and Fang Liu Chalmers.
6. At DTU, April 14, 2016; present Lennart Johanson and Torsten Kern, Siemens; John Hald, Kristian Vinter Dahl, Irina Fedorova, Chitta Ranjan Das, and Frank Niessen, DTU; and Masoud Rashidi, Robert Lawitzki, and Hans-Olof Andrén, Chalmers.
7. At Chalmers, September 13, 2016; present Lennart Johanson and Torsten Kern Siemens; John Hald, Irina Fedorova and Chitta Ranjan Das, DTU; and Masoud Rashidi, Fang Liu and Hans-Olof Andrén, Chalmers.

Planned activities: (3-4 lines)

We will continue to work on the phase transformation from MX to Z-phase in the steels, in particular to gain deep insights on the effects of carbon on the phase transformation.

Appendix

Table 1. Chemical composition of ZU1-3 trial steels in weight and atomic % (Fe in balance).

	Ni	Co	Cr	W	Ta	Nb	C	B	N	Si	Mn	Cu
ZU1(wt%)	0.18	2.7	11.1	2.1	0.39	–	0.037	0.0048	0.053	0.35	0.13	2.0
ZU1(at%)	0.17	2.57	12.0	0.64	0.12	–	0.17	0.025	0.21	0.70	0.13	1.77
ZU2(wt%)	0.17	3.1	11.1	2.1	0.22	0.15	0.04	0.0054	0.053	0.33	0.14	2.0
ZU2(at%)	0.16	2.96	11.99	0.64	0.07	0.09	0.19	0.028	0.21	0.66	0.14	1.77
ZU3(wt%)	0.20	3.1	11.2	2.47	0.38	–	0.06	0.0045	0.056	0.22	0.15	–
ZU3(at%)	0.19	2.96	12.14	0.76	0.12	–	0.28	0.023	0.23	0.44	0.15	–

Reporting period:

Status report KME

Project title: Combating superheater corrosion by new materials and testing procedures - Corrosion experiments in the waste fired CFB boiler P15 at Händelö.

Project no: KME-711

Project manager: Jesper Liske, HTC/Chalmers

PhD:s/lic:s: Dr. T. Jonsson (5%), Dr. J. Liske (20%), Dr. L. Paz (40%), A. Olivas (40%)

Project goals:

The overall goal of the project is to improve plant economy by enabling an increased green electricity production and optimum material selection. The material matrix includes commercial steels available today as well as future materials developed for this type of environment. This will be achieved by generating new knowledge about the following topics:

- To correlate the corrosivity of the flue gas with the flue gas temperature in respect to the material temperature.
- To verify and quantify the corrosion rates for different superheater materials in superheaters with a horizontal design.
- Verify and compare the corrosion properties of commercial superheater materials as well as state-of-the-art stainless steels and FeCrAl alloys.
- Verify and compare the corrosion properties of coatings performed with the new generation coating technology HVAF (High Velocity Air Fuel).

- Compare different corrosion testing methods (i.e. probes, coils/tubes and clamping) with respect towards their complexity, cost and plant availability risk.

Project goals in relation to KME goals

This project proposal contributes to the following KME goals:

- Verifying novel solutions in boiler design with respect towards corrosivity.
- Increased steam parameters and thereby higher electrical efficiency.
- Test improved material solutions – including alumina forming alloys and coatings.

Progress in relation to project goals:

- Verifying novel solutions in boiler design with respect towards corrosivity.

This goal is primarily directed towards investigation of the corrosion attack of a horizontal SH bank. We have during 2015 installed new clamp samples and tube samples in this section as well as removed the first set of exposed clamp samples from the boiler. The samples has been exposed for approx. 6400 hours. During this revision, new clamp samples as well as tubes were installed. The clamp samples included FeCrAl model alloys. The exposed clamp samples have been evaluated by Chalmers and AmecFosterwheeler. The results show that the corrosion rate is rather low, which was expected since the material temperature has been rather low (360 °C and 380 °C). This was also true for low alloyed steels, i.e. the corrosion rate was low regardless of material. The samples that has been exposed for a total period of 2 years has been dismantled during spring 2016 and are currently being analysed. However, there are no definitive conclusions made yet.

- Increased steam parameters and thereby higher electrical efficiency.
- Test improved material solutions – including alumina forming alloys and coatings.

The clamp samples has been exposed at different material temperatures, however, the difference in temperature between different samples was lower than expected, only 20 °C. Thus, the comparison between different temperatures for long term testing may be slightly vague. Clamp samples of model FeCrAl alloys has been installed during this revision and will be analysed after long term exposure. The selection of model alloys has been done in close collaboration with Sandvik Heating technology as well as KME709 and HTC 1a "Critical corrosion phenomena". In addition, both HVOF and HVAF coated samples has been exposed as clamp materials.

The short term testing is now planned in detail and will be started in week 42. For short term testing (24 hours and 168 hours), we will test materials at both 400 °C and 600 °C, which gives a much better knowledge about the

effect of the corrosion performance of materials at higher temperatures. For the 600 °C exposure, FeCrAl model alloys as well as a new stainless steel (Sanicro 33) will be investigated. At 400 °C, more "ordinary" steels will be used such as T22 and 347H. However, these will undergo different types pre-oxidation prior to the exposure in the boiler. The pre-oxidation well be done in collaboration with the HTC project "Critical corrosion" and the aim is to improve the knowledge of how chlorine is able to penetrate the oxide scales.

Summary over results and work so far (max 1/2 A4-page):

The analysis of the first set has been finalized and the conclusion is that the corrosion rate is very low during this 6400 hours exposure. The reason for the low corrosion rate is explained by the low temperature of the superheaters in the boiler (and thus, low temperature of the clamp samples). The analysis of the year 2 clamp samples are currently ongoing. However, no results from the latter clamp samples are presented yet.

The effect of start-up sequence of probe exposures were tested, analysed and reported during 2015. The results were presented by Chalmers on the 22nd FBC conference held in Tampere Finland in June 2015. The results indicated that the start-up of probe exposures can be performed as they are done today, i.e. inserted directly into a hot boiler.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

Yes, on the project as a whole. However, some companies is slightly behind in reporting their in-kind contribution and Chalmers is also slightly behind in their costs. Chalmers estimates that the budget over the year will be fulfilled as more work is planned for the second half of 2016 compared to the first half.

The time schedule is according to plan.

Number project reference group meetings held until report date:

One reference group meeting 22/10 2015 at Chalmers. Another reference group meeting is planned for 6/12. This activity is synced with the KME projects KME709, 714 and 720.

Planned activities: (3-4 lines)

We plan to withdraw the third set of clamp samples from the boiler during the spring 2017.

The planned short term tests (corrosion probes, in-situ alkali measurement, in-situ corrosion probe, deposit probe) will start in week 42 2016. These exposures will be combined with thermodynamical calculations performed by Högskolan I Borås.

Date
2016-09-30

Reporting period:

Status report KME

Project title: Sulfur recirculation and improved material selection for high temperature corrosion abatement - Investigating different aspects of corrosion memory

Project no: KME-714

Project manager: Torbjörn Jonsson, Chalmers

PhD:s/lic:s: T. Jonsson (20%), J. Phother (30%), L. Paz, J (30%), J. Liske (10%),

Project goals:

- Increase green electricity production from combustion of biomass and waste.
- Improved fuel flexibility.
- Improved material design/selection

Progress in relation to project goals:

Måbjergverket has changed owners during the project period. This resulted in an updated time plan that has been approved by SEA. The work follows the updated project plan.

Summary over results and work so far (max 1/2 A4-page):

Summary of the activates at Måbjergverket: The sulfur recirculation installation at MEC line 1 in Holstebro consists of two systems:

1) *Desulphurisation with hydrogen peroxide for producing sulfuric acid in the existing scrubber.* This system consists of a 40 m^3 hydrogen peroxide storage vessel, dosage pump, piping and instrumentation resistant to sulfuric

acid. It was successfully started and operated 7-14 September, when line 1 (sulfur recirculation) was taken into planned maintenance stop. During this time we produced some 35 m^3 of 4 wt% sulfuric acid.

2) *Injection of sulfuric acid into the boiler.* The mechanical installation is nearly complete. It consists of a pump, a 170 m long sulfuric acid transport pipe and two injection lances. Electrical installation is ongoing and will be completed in time for the startup on October 14th, when injection of the already produced sulfuric acid will start.

Installation of superheater test materials and a boiler hatch with 3 sample ports for corrosion probe testing will also be installed before startup on October 14th.

Line 2 (reference operation) will have maintenance stop during W43, when superheater test materials and boiler hatch with sample ports will be installed.

New corrosion probes have been constructed and all samples for the exposure are prepared.

Activates at DTU: Corrosion tests on heat treated steel with Cr rich precipitates (700^{o}C for 3000h) vs untreated samples has been undertaken. The material tested consists of 23.8 Cr, 22.0 Ni, 2.77 Cu, 2.46W, rest Fe.

The specimens have been exposed for 600^{o}C and 168 hours in an atmosphere of 15 % H20, 5 % O2 and balance N2, with a coating of KCl or partially submerged in KCl deposit.

Results confirm the initial theory that there is more attack of the aged material, and microscopy reveals preferential attack at or within the precipitates.

The laboratory work is supported by thermodynamic assessments using ThermoCalc revealing the stability of phases.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations: The project follows the updated project plan/budget. However some companies are slightly behind with in-kind reporting.

Number project reference group meetings held until report date:

A reference group meeting was held (2015-22/10). The next meeting is planned to be held at Chalmers during December.

Planned activities: (3-4 lines)

Maintenance stop in September-October: Material samples will be installed in the super heaters of both line 1 (Sulfur Recirculation) and line 2 (Normal operation) in order to enable comparison of the corrosion rates. The aim is to start the probe exposures week 46 and in connection to that have a project meeting at Måbjergverket.

To understand corrosion attack of carbide precipitates observed in the laboratory, corrosion testing of chromium carbide coated steel will be conducted.

Date
2016-09-20

Reporting period: Q1-Q3 2016

Status report KME

Project title: Composite Metal Polymer for non-stick for improvements in CHP plants.

Project no: KME-715 (EM project no 40040-1)

Project manager: Matti Huhtakangas

PhD:s/lic:s: (working in the project and degree of activity)

Project goals:

Goal 1: Investigating the possibility to increase the electrical efficiency through decreased amount of deposits,
which minimise losses from decreased heat transfer and frequent soot-blowing, as well as through lowered inlet
temperature to the economiser enabled by increased resistance to low temperature corrosion.
Goal 2: The research facilitates, as a main goal, the development of a technique for applying Composite Metal
Polymer (CMP) in a plant, which is a new material solution.
Goal 3: Performs and evaluates exposures and application tests of composite materials in the form of a coating.
The aim is to increase both the fuel flexibility through minimising the problems related to fuels giving substantial
amounts of deposit, and to increase the electrical efficiency through decreased need of soot-blowing and lower
economiser inlet temperature.
Goal 5: Evaluates and investigates a new material solution that in different variants will contribute to minimising
especially low temperature corrosion, but also superheater and furnace wall corrosion, as well as erosion
problems.

Goal 6: The research facilitates the development of a new composite based design solution that will increase fuel
flexibility and plant availability through minimised down-time caused by damages related to corrosion and
soot-blowing related erosion, as well as caused by excessive deposits causing failure or blockage of for example
electrostatic precipitator filters, fan blade, and ash release cones.

Progress in relation to project goals: The progress is according to plan except that the delayed installation of field test samples at a Dong Energy plant will prevent these samples to be inspected more than one time. Activity 3, "*Laboratory investigation of the temperature capability of the polymer when being part of a CMP during exposure in humid atmosphere*", has been postponed in order to get further feedback from Activity 2 and will be carried out during 2017.

Summary over results and work so far (max 1/2 A4-page):

Candidate CMP materials has been selected as follows;

1. ALU-Releco, AR107/102 PTFE
2. ALU-Releco, AR-150 ceramic
3. Diamant Metallplastic, Dichtol HTR
4. FMP Canada, BN-silicate
5. FMP Canada, Al-phophate/BN, cancelled
6. Millidyne, Avalone non-stick
7. Millidyne, MDS-HT1
8. Aremco, CP4020 S1
9. Aremco, Pyopaint 634 BN
10. Aremco, Pyropaint 634 GR

CMP laboratory samples is manufactured from each candidate.

CMP samples installed at Öresundskraft Vesthamnverket as follows;

ESP (electrostatic precipitator) cone plate samples, candidates 1,2, 3 and 6.

Economizer ½-tube samples, candidates 1 and 6

Low temperature superheater ½-tubes samples, candidates 3, 7 and 8

High temperature superheater ½-tubes samples, candidates 4, 5, 9 and 10

Furnace wall ½-tubes samples, candidates 2, 4, 5 and 9

These materials have been delivered to Swerea KIMAB for further examination.

CMP samples installed at Avedoreverket as follows;

2nd pass below ECO 2, candidates 4, 7, 9 and 10

3rd pass inside ECO 1, candidates 3, 4, 7, 8

3rd pass after ECO 1, candidates 2, 3, 4, 8

Wear tests were performed for materials 1, 2,3,4,6,7,8,9, 10 for the total time periods of 30 min, 2 h and 10 h. Shorter stops were made in all exposures to enable photographs of the tumbled samples. Stops were made after 30 min, 60 min, 120 min, 240 min, 360 min and 600 min. Material 10 was excluded from the short term tests since visual inspection after 30 min in the 10 h test showed very poor adhesion of the composite layer.

For materials 1, 6 and 8 (polymer containing materials according to information available), droplet tests with water at room temperature were performed before and after the wear tests. These results indicate some difference in wetting angle before and after the wear tests. However, no clear indication of differences between the various exposure times was as yet analysed.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations: Yes, but if Dong decide not to attend the in-kind of Sek 150000 will need to be re-planned.

Number project reference group meetings held until report date:

No. 1 at Öresundskraft, Rikard Norling Swerea KIMAB, Henrik Wangsell and Fredrik Joelsson Öresundskraft, Matti Huhtakangas, Kristian Huhtakangas and Sören Stutin MH Engineering.

Various test locations was discussed and formally agreed on, ended with plant tour to identify the locations and most suitable place.

No. 2 at Dong Avedore, Rikard Norling Swerea KIMAB, Sören Jensen and Jan Hansen Dong, Matti Huhtakangas, Kristian Huhtakangas and Sören Stutin MH Engineering.

Various test locations was discussed and plant tour to identify the alternative locations. MHE to return with candidate proposals.

No. 3 at Swerea KIMAB, Ragna Elger Swerea KIMAB, Matti & Kristian Huhtakangas MH Engineering.

Wear test to identify the "equilibrium" stage for the polymer part was discussed and concluded by number of steps after which the materials should be investigated before further wear test.

Planned activities: (3-4 lines)

Following tests should be done for each candidate CMP material (materials 1, 6, and 8);

▪ Microscope analysis of materials 1, 6 and 8 including penetration depth.

- Take-out of first set of field samples at Öresundskraft made during spring 2016;

  ▪ Analysis of exposed samples at Swerea KIMAB.

Date
2016-04-17

Reporting period: 1st Jan 2016 – 30th June 2016

Status report KME

Project title: Intermediate temperature corrosion in used-wood fired boilers – the influence of lead, zinc and their chlorides

Project no: KME-717 (EM project no 40892-1)

Project manager: Rikard Norling

PhD:s/lic:s: Annika Talus (15% activity)

Project goals:

A specific goal of the project is to find out if lead, zinc and their chlorides causes serious corrosion problems in the temperature range 150- 420°C in boilers firing used wood, and if the attack is worsened by the use of additive that reduce alkali chloride corrosion on superheaters at higher temperatures. Based on the knowledge acquired by full-scale probe testing and the results of modelling and laboratory testing solutions for minimizing potential problems will be suggested.

Progress in relation to project goals:

The progress follows the project plan.

Summary over results and work so far (max 1/2 A4-page):

The work follows the project plan. First series of full-scale probe testing has been performed. Analysis of the samples is ongoing. Modelling of the test conditions is ongoing.

The analysis results have shown that trends in deposit chemistry exist with relation to temperature and the use of additive.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

No deviations.

Number project reference group meetings held until report date: 1

A combined project and reference group meeting was held 2nd June 2016.

Planned activities: (3-4 lines)

Start of laboratory testing at Åbo Academy during the autumn 2016.

Forthcoming work includes new probe testings.

Date
2016-10-04

Reporting period: 1st Jan 2016 – 30th June 2016

Status report KME

Project title: High temperature corrosion in used-wood fired boilers – fuel additives and coatings

Project no: KME-718 (EM project no 41515-1)

Project manager: Rikard Norling

PhD:s/lic:s: Annika Talus (5%, project in start-up phase)

Project goals:

The overall aim of the project is to reduce operation and maintenance costs in heat and power boilers that burn predominantly used (recycled) wood by the use of additives to the fuel and the use of new coating materials. The effort will be directed towards furnace walls. In general this will result in increased fuel flexibility and make biomass a more attractive and financially competitive energy source.

Specifically the project aims at acquiring new knowledge from longer term studies on the effect of using sewage sludge as fuel additive on furnace wall corrosion. It further aims at finding a sludge that can be used as an alternative to sewage sludge and investigate the effects of it and evaluate whether it is suitable for longer term use.

The project aims at acquiring in-depth knowledge on the corrosion behaviour of materials typically used for furnace walls both when fuel additives are used and when firing the reference fuel. It also aims at investigating the corrosion properties of some new coating materials and their related performance with respect to furnace wall protection.

The academic goal of this project includes one licentiate (Annika Talus), as well as giving additional contribution to her PhD thesis (estimated 2018). The results will be published in one to two scientific papers.

Progress in relation to project goals:

The progress follows the project plan.

Summary over results and work so far (max 1/2 A4-page):

A 2-weeks exposure with sewage sludge has been performed. Two corrosion probes at furnace wall position and one super heater deposit probe have been exposed. The super heater deposit probe has been evaluated with respect to deposit growth and deposit composition. The chlorine content in the furnace probe deposits has also been evaluated. The addition of sewage sludge looks promising with lower deposit growth rate and low chlorine concentration in the deposit.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

No deviations.

Number project reference group meetings held until report date: 0

Planned activities: (3-4 lines)

Forthcoming probe exposures are being planned.

A coated wall tube has been installed in the Blackburn Meadows Plant in UK as part of KME-708. It will be evaluated after a long-term exposure (>1 year) within KME-718.

Date
2016-09-29

Reporting period: January-June 2016

Status report KME

Project title: Development of weldability assessment and understanding of hot cracking in boiler and gas turbine materials

Project no: KME-719 (EM project no 40893-1)

Project manager: Lars Nyborg (+46 31 772 12 57, lars.nyborg@chalmers.se)

PhD:s/lic:s: A PhD student (Sukhdeep Singh) has been recruited and is now fully engaged in the project.

Project goals:

The overall goal of the project is to increase the overall understanding of hot cracking mechanisms as well as to develop weldability testing capability towards hot cracking in a reliable way. At the end of project, we expect to have a testing methodology both from theoretical and practical point of view that can be used as generic means of assessing weldability of high temperature materials.

Academic goals

The academic goals are the following:
1. To accomplish a licentiate engineer
2. To develop a unified theory for hot cracking
3. To develop a testing rationale for hot cracking

Industrial goals

The industrial goals are the following:
1. To generate weldability test data on materials relevant to the boiler industry
2. To recommend materials and parameters for improved weldability
3. To establish a testing methodology that can be used for assessing weldability with respect to hot cracking susceptibility

Progress in relation to project goals:

The project proceed according to outlined project goals.

Summary over results and work so far (max 1/2 A4-page):

During the first year of the project, an extensive literature study have been performed covering hot cracking in nickel-based superalloys and austenitic stainless steels. A review paper titled “Review of hot cracking phenomena in austenitic stainless steels” was made out of this study and will be published in the Swedish Symposium 2016. Parallel to this, experimental work have been carried out focusing on hot cracking in cast alloy 718. Varestraint tests were performed on a large amount of tests plates of cast 718. Cracks forming either in the fusion zone and heat affected zone were quantified. Analysis was conducted using optical microscopy and scanning electron microscopy. Further tests included hardness measurements and estimation of volume fraction of secondary phases. The preliminary results from this study have been submitted and presented at the IIW meeting in Melbourne Australia. The complete work is planned to be submitted to a scientific journal by the end of the year. Another conference is planned for, Swedish Aerospace Technology in Stockholm, however this will not result in any publication. As part of the Phd studies, the student has taken courses covering 18 credit points (27 credits are planned for by the end of year).

A project meeting was held at Amec Foster Wheeler in Finland. The meeting resulted in discussion of the project relative to the boiler applications side and acquisition of the material for testing. Alloy 347 sheet material have ordered and we are now also looking into availability of HR3C sheet material. A Gleeble machine has been acquired by University West and is now to be installed in October. the machine will be utilized within the project. An upgrade of the Varestraint testing machine will also be carried out.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

The budget is according to plan both at the university and significantly ahead at the industry.

Number project reference group meetings held until report date:

Two project meetings have been held with GKN. A second meeting together with AMEC has been held at their site.

Planned activities: (3-4 lines)

1. Finish the analyses of the Varestraint tested 718-samples
2. Presented the review paper on stainless steels at the SPS-conference in Lund
3. Acquire all the relevant stainless steel material

4. work on a new testing rationale for Gleeble testing and Varestraint weldability testing
    a. make an upgrade of the Varestraint testing machine
5. Make a presentation at the Aerospace conference in Stockholm in October

Date
2016-09-30

Reporting period:

Status report KME

Project title: The effect of increased fractions of waste wood on water wall- and superheater corrosion - Combating corrosion by new materials and improved material selection

Project no: KME-720

Project manager: Jesper Liske, HTC/Chalmers

PhD:s/lic:s: Dr. T. Jonsson (5%), Dr. J. Liske (20%), Dr. L. Paz (30%), J. Eklund (5%)

Project goals:

The overall goal of the project is to improve plant economy by enabling an increased green electricity production and optimum material selection. The material matrix includes commercial steels available today as well as future materials developed for this type of environment. This will be achieved by generating new knowledge about the following topics:

- To verify and quantify the corrosion rates for different superheater materials in superheaters with a horizontal design.
- Verify and compare the corrosion properties of a biomass fired boiler (Örtoftaverket) and waste fired boiler (Händelöverket in KME711/EM39299-1)
- Investigate how the corrosion performance of water walls is affected by a stepwise increase of the waste wood fraction in the fuel mix.

Project goals in relation to KME goals

The goals of this project is direct related to the following goals stated in the program description:

Goal 3:

This project will explicitly examine several materials and their corrosion resistance when the fuel mix changes. The results will contribute to improve the material selection of superheaters and water walls so that materials with extended lifetime can be selected alternatively an extended fuel flexibility can be achieved. The results may also be used by material manufacturers to produce steel with optimized microstructural characteristics which better prevents the corrosion caused by the corrosive environment.

Goal6:

This project will investigate how the corrosion rate of several different steels/alloys changes with different fuels. With this knowledge, fuel flexibility and/or availability may be increased. Through an improved understanding of how corrosion is influenced by environmental and material-specific parameters new boiler designs, operating parameters and tools can be proposed.

Progress in relation to project goals:

We have since the last status report withdrawn the first sets of clamp samples from the boiler. This was done during the summer revision. The analysis of the clamp samples are currently ongoing at Chalmers. However, no results from the analysis has been presented yet.

Summary over results and work so far (max 1/2 A4-page):

The work so far has primarily been constituted towards planning, installation and removal of clamp samples. The first year clamp samples are now being analysed. The second year clamp samples were installed in the boiler during the summer revision is currently being exposed. The clamp samples exposures and analysis is following time and cost plan.

In addition, planning/discussions of the upcoming short term corrosion probe testing in the superheater region and planning of the water wall corrosion probe testing has been performed (see below).

Is time schedule and costs according to plan/budget? Comments over reasons if deviations:

At the moment the costs, budget and time plan are according to plan. However, there some deviations, see below. This has resulted in lower costs at Chalmers compared to budget as well as lower in-kind contribution for some of the companies. Also, not all companies has reported their in-kind contribution to this date. The project manager is reminding these companies. Despite this deviations, the estimation is that the project will fulfil budget and in-kind contributions until the project ends. If there are no possibility to perform water wall corrosion probe testing (see below) this estimation probably needs to be revised.

<u>Deviations:</u>

For the short term exposures, the planning has proceeded and the exposures are planned to be executed during first half 2017. Unfortunately there seems to be no possibility to access the IACM (alkali chloride monitor) to these tests.

Instead we will deploy FTIR measurements of the flue gas in order assess its corrosiveness.

The part in the project dealing with water wall corrosion has unfortunately been delayed. The reason of the delay is related towards to whom will account for the risk of doing modifications to boiler (a new hole in the water wall needs to be constructed in order to be able to perform water wall corrosion probe testing). Since this issue were not resolved in time (for the revision) the water wall tests are delayed until next revision (summer 2017). This delay is not expected to jeopardize the overall project time plan but some activities (primarily analysis and evaluation on the Chalmers side) needs to be adjusted in time. There is also a risk that the responsibility issue (i.e. owner of the risk) will not be solved. If this scenario occurs, part of the project plan needs to be revised. However, there discussions ongoing between the project manager and industrial partners and the estimation is that this issue will be resolved.

Number project reference group meetings held until report date:

One reference group meeting 22/10 2015 at Chalmers. Another reference group meeting is planned for 6/12. This activity is synced with the KME projects KME709, 711 and 714.

Planned activities: (3-4 lines)

We are performing corrosion analysis of the first year clamp samples. The plan is to withdraw the second set of clamp samples from the boiler in the summer of 2017. The short term probe testing campaign is planned for being executed during the first half of 2017.