

Date
2016-04-06

Reporting period: September 2015 – December 2015

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: Sten Johansson

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

Mattias Calmunger 100%

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 and 1.2 are in progress relating to the main purpose and the first goal by performing and later evaluating specified tests. In relation to the second goal the ageing is finished, the mechanical testing are in progress and almost finished. Some analysis have 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. Mattias Calmunger successfully defended his PhD-thesis "On high-temperature behaviors of heat resistant austenitic alloys" the 21th of December 2015.

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

Creep/LCF interaction testing in strain control at elevated temperature of Sandvik Sanicro™ 25 has been reported in a paper published in Trans. Indian Inst. Met. 69 (2016) p. 337-342. The results show that the introduction of dwell time causes a larger plastic strain range. Fig. 1 displays hysteresis loops from the LCF test without (Fig. 4a) or with 30 min (Fig. 4b) dwell time. Stress relaxation due to the dwell time is observed at each strain maxima in Fig. 1b. The low degree of stress relaxation, 36 MPa in tension and 26 MPa in compression, in the first cycle in Fig. 4b is attributed to the lower maximum stress levels of the first cycle. As a consequence of the relaxation a larger inelastic strain range occurs, shown in Fig. 1.

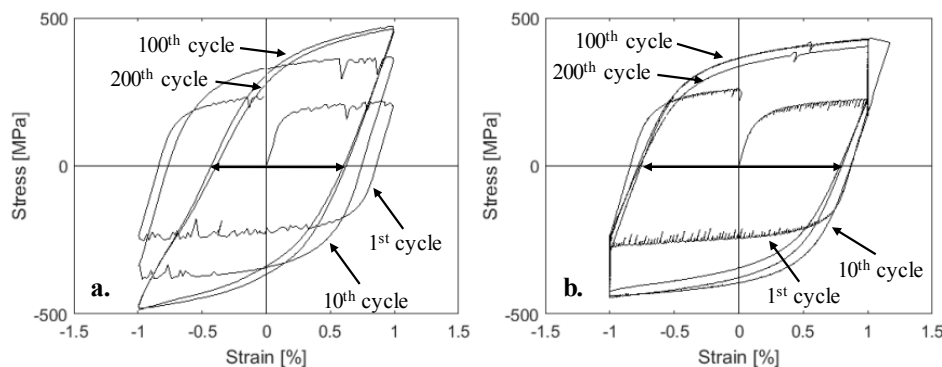


Figure 1: Hysteresis loops at 700 °C, using strain range of 2 % and two dwell times. a Dwell time 0 min. b Dwell time 30 min. The inelastic strain ranges corresponding to the 100th cycle are pointed out by the double arrows.

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 and Task 1.2 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 at Swerea KIMAB is planned to the 20th of April with all project participants represented. Last meeting were held in Linköping the 18th of May 2015.

Planned activities:

The TMF testing (task 3.2) is planned to be started in May. Toughness tests after long-term ageing (task 2.1), creep/LCF interaction tests (task 1.1) and slow strain rate tensile testing (task 1.2) are also planned to be performed.

Reporting period: July 2015 – December 2015

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) have been started. IP and OP TMF between 100-750°C have been considered so far. Both STAL15 and IN792 are under investigation.
- Microstructure investigations have been performed 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 at 500°C with lower initial load compared to the previous report. The testing is performed on miniature size DCT-specimens with three different orientations. Testing has been performed also at 750°C. An example of the results at 500°C can be found in the figure below.

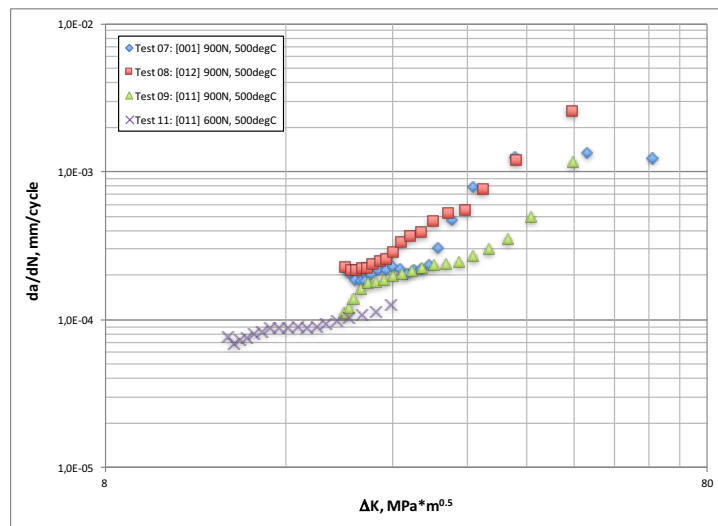


Fig 1: Crack propagation rates in STAL15 for samples with different orientations and initial stress intensity factor ranges (ΔK)

Regarding the modelling part of the project; the elastic and plastic anisotropy of the single-crystal materials bring many difficulties in terms of modeling, evaluation and prediction of fatigue crack growth. We adopted a single-crystal material model to a finite element-environment, which is paired with a crack growth tool (FRANC3D). All simulations are performed 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. The influence of the crystal orientation, as well as the influence of misalignments of the crystal orientation due to the casting process are

investigated. It is shown that both the crystal orientation and the misalignment from the ideal crystal orientation are important for the crack driving force. The realistic maximum limit of 10° misalignment is considered. It can be seen that crack growth behavior is highly influenced by the misalignment. This methodology is now used to develop a criterion which indicates a change in cracking mode from macroscopic modulus I to crystallographic cracking.

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:

Four 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.
- 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

Reporting period: July – December 2015

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 resistance to TCF and oxidation is almost complete for two Ni-base and partly done for one Co-base coating systems.

Tasks 3 directly related to goal 3 is under way.

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 isothermal oxidation tests on the Ni-base are almost complete except for the 10000h test (due to an accident when reaching 8000h, the test was restarted). The positive effect of Ru on resistance to interdiffusion and negative effect of Ce on surface oxidation were shown. TCF and isothermal oxidation tests for 1100 C on the Co-base system is complete and isothermal test for 1000 C and 900 C are ongoing. The results on the Ni-base coating system is published in a conference paper.

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 almost 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.

Preparation work for DBTT and TMF tests is done.

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.

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 delayed but 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

Planned activities: (3-4 lines)

1. Post-testing analysis of the isothermal aged and TCF tested Co-base coatings
2. Continuing isothermal aging and TCF tests
3. DBTT and some TMF test of coated specimens
4. Further work on the oxidation-diffusion model

Reporting period:

Status report KME

Project title: MoSi₂ 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 high corrosion resistance MoSi₂ based composites for furnace and gas-turbine combustion chamber components aiming at operation temperatures $\geq 1200^{\circ}\text{C}$.

Progress in relation to project goals:

Fracture toughness KIC was measured on the cylinder shaped testing pieces using Single Edge V – Notch Beam (SEVNB) technique developed at Mot CHT. The development provides an accurate method for fracture toughness KIC of intermetallic and ceramic materials applied for HT corrosion and oxidation environments.

Thermal cyclic oxidation was performed on the final sintered MoSi₂-ZrO₂ composite.

New MoSi₂-SiC and (Mo,Al)Si₂-SiC composites were manufactured using a pressure-less sintering (PLS) method. Sagging oxidation test was conducted on this composites at HT. The new composite aims to strengthen the C40 (Mo,Al)Si₂ material to high creeping resistance at HT, taking the advantage of the Al-alloyed C40 silicide on excellent resistance against petting oxidation and reducing atmosphere at medium and high temperatures.

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

KIC of a pre-sintered $\text{MoSi}_2\text{-ZrO}_2$ composite at Mot CHT was measured. A high accuracy of KIC was obtained in comparison with the results from NPL UK. It is indicated the technical satisfaction on V-notch quality and flexure fixture design. The deviation in the measurement is believed to attribute to a large loading scale of the loading cell.

Thermal cyclic oxidation at 1200 and 1300°C on the final sintered $\text{MoSi}_2\text{-15%ZrO}_2$ composite shows excellent thermal shock and oxidation resistance superior to the as-sintered counterpart. The final sintering is an efficient technique to remove the as-sintered surface produced during PLS.

SiC reinforced composites $\text{MoSi}_2\text{-SiC}$ and $(\text{Mo,Al})\text{Si}_2\text{-SiC}$ were manufactured with SiC additive contents of 5, 10, and 15 %. The materials were sintered at 1620 and 1700°C, respectively. Sintering density up to 97% theoretical density was achieved. Sagging test was taken at 1700°C for 100 h in air, compared with $\text{MoSi}_2\text{-ZrO}_2$ composite and state-of-the-art Kanthal Super HT material. The result shows that the $\text{MoSi}_2\text{-10%SiC}$ composite presents with high oxidation resistance and lower deformation rate close to Kanthal Super HT. Heavy oxidation occurred on $(\text{Mo,Si,Al})_2\text{-SiC}$ during sag testing. It is believed that final sintering is necessary to produce a protective oxide prior to sag test.

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 reference group meeting is arranged on 13/04.

Planned activities: (3-4 lines)

- A new loading cell with low loading force will be booked for KIC measurement. The cost will be shared with other research projects in Mot CHT.
- Microstructural characterization of as-sintered and oxidized $\text{MoSi}_2\text{-SiC}$ and $(\text{Mo,Al})\text{Si}_2\text{-SiC}$ composites starts in April 2016, and RT mechanical testing before summer.
- Prepare $\text{MoSi}_2\text{-10SiC}$ and $(\text{Mo,Al})\text{Si}_2\text{-10SiC}$ materials and conduct final sintering in September 2016, sagging and cyclic tests in January 2017.
- Attend *International Symposium on Advances in Materials Science 2016*, in August 2016.
- Complete the article for the final sintered $\text{MoSi}_2\text{-ZrO}_2$ composite in December 2016.

Date
201-04-04

Reporting period: Juli-December 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):

An extensive set of Gleeble testing were performed at the University of Manitoba (UoM) in Canada during the last reporting period which now have been be evaluated by the Phd student. Tests that were carried out at the at the Advanced Photon Source in Chicago, USA, have partly been analysed and a paper is now ready to submit to a distinguished journal. Another initiative on another paper has been started as well. GKN performed significant amount of repair welding and heat treatment on wrought Haynes 282 which the PhD student is evaluating. Some preliminary results were presented at the International Institute of Welding (IIW) intermediate meeting in Madrid and will finally be presented at the IIW annual meeting in Melbourne, Australia, this summer. A review paper is also being written and will be presented at the Swedish production symposium (SPS) in Lund now in October.

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:

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

Planned activities: (3-4 lines)

1. Carry out 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
4. Put up a new testing rationale at the Gleeble testing machine at University West/Chalmers University of Technology
5. Finish the review paper which will be presented at the SPS-conference in Lund
6. Make a presentation at the Aerospace conference in Stockholm in October

Date
2016-03-29

Reporting period:

Status report KME

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

Project no: KME-707

Project manager: Magnus Genrup

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 –

M3 – Srikanth defended Licentiate as scheduled on 27th of October 2015

D4 – Project status report completed

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

- **Update on the tasks from previous report :**

Airfoil design philosophies for stator and rotor of stage 16 of IP section was taken up. For the stator, relatively aft-loaded airfoil provided better performance in terms of total pressure loss and efficiency. In rotor, front loaded airfoil was beneficial when compared to the baseline case.

Further, modification in flow path was looked at. Axisymmetric end wall contouring which is invariably present in all the stages was analysed for its contributions to performance. A very simple tip shroud was modelled for initial

analysis and was found that endwall contour significantly controls the tip leakage loss. However, the results cannot be generalized for all the tip shroud configurations. Actual tip shrouds from the machine may provide different conclusion which needs to be analysed.

- **Tasks after the previous report :**

Two papers were accepted for ASME conference publication after the previous report. Both will be presented in Turbo Expo 2016 to be held in Seoul, South Korea from 13th June to 17th June.

SIT Finspang provided the geometry for HP front stages (short stages) and the work has commenced resulting in completion of baseline analysis as on date. Fidelity of the models have been increased by incorporating leakage flows. Actual geometries from the machine have been modelled using structured grid. Further plan is discussed under planned activities

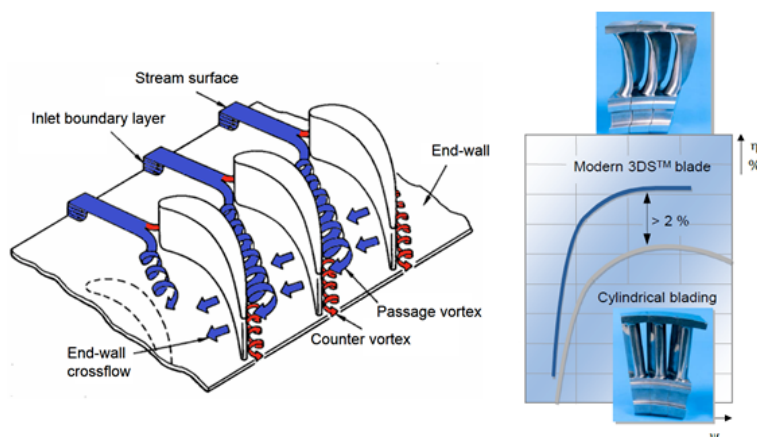
Is time schedule and costs according to plan/budget? Comments over reasons if deviations: See below.

Number project reference group meetings held until report date: 2 full and 4 technical. In the recent one held in Feb 2016, it was decided to shift the focus from the tall stages in IP section of turbine to short stages in HP section in turbine.

Planned activities: (3-4 lines)

Planned activities are as follows

- Incorporate 3DS design on the stage 2 rotor. This is with the target of reducing the secondary losses. With the open literature available, it can be understood that 3DS designs involve end bends of rotor blade along with vortexing. This is expected to give higher gain in efficiency than the taller stages.



- Corresponding stator modifications in order to align the flow to the rotor.

- Rotor vortexing in taller stages to further improve on the gained efficiency.
- Rotor vortexing and compound leaning on rotor will be studied to reduce secondary losses in rotor.
- All design modifications will be numerically analyzed in multistage environment.

List of publications under KME project:

1. Efficiency Improvements In An Industrial Steam Turbine Stage - Part 1 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 2 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 the ASME 2015 Gas Turbine India Conference, GTINDIA2015, December 1-3, 2015, Hyderabad , India
4. Vortexing Methods To Reduce Secondary Losses In A Low Reaction Industrial Turbine. 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 the ASME 2014 Gas Turbine India Conference, GTINDIA2014, December 15-17, 2014, New Delhi, India

Date
2016-03-18

Date: July 2015 – December 2015

Status report KME-708 (EM 39270-1)

Project title: High temperature corrosion in waste-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%

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:

Testing to support goal (1) is 50% complete.

Testing to support goal (2) is 75% complete. Long-term testing in a power plant has been completed. The results have been analysed. Laboratory testing and some detailed microscopy remains.

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

Progress is being made on all 3 goals.

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. Laser cladded coatings performed well.

Corrosion testing of coating alloys for furnace walls is still continuing with a variety of alloys from Sandvik Heating and Materials Technology. Sandvik Heating Technology has developed welding procedures for cladding furnace tubes with the FeCrAl alloy APMT.

Full scale fuel quality testing was performed in Nyköping with two different used wood compositions (low Cl and high Cl, but both in the range 0.1-0.2 wt%). Results showed that small differences in chlorine content of the fuel resulted in large differences in chlorine content of the deposits and furnace wall corrosion rates (more Cl gives a higher corrosion rate).

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 ahead of plans. E.ON and Vattenfall have performed a lot of testing at their plants, due to favourable conditions - no plant shutdowns and good availability of staff.

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. This was combined with a visit to the plant and the opportunity to go inside the boiler.

Planned activities: (3-4 lines) Planned activities for January - June 2016.

A combined project/reference group meeting held in May or June

Last series of wall probe corrosion testing in Nyköping

Short-term laboratory- scale testing in SP's FB rig with fuel from Nyköping.

Installation of a furnace wall tube coated with APMT in a used wood fired boiler.

Starting the microscopy on the corrosion specimens with High Cl , low Cl fuel. Preliminary comparison of full-scale and laboratory exposure.

Date

2016-04-04

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 during the revision 2015-09 and new materials mounted in accordance with the project plan. A part of the un-cooled FeCrAl tube was in addition cut for analysis. 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 the samples will be 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.

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

The Steamboost material has been exposed for one year in the boiler in accordance with the project plan as well as an un-cooled FeCrAl tube. The materials have been analysed by thickness measurements and SEM/EDX (selected samples). We have in addition performed deposit test and selected a setting of the boiler. The newly developed probe has been used during short and long corrosion test. All these exposures have generated a large amount of samples. Some of the samples have been analysed but we are now working on performing a majority of the analyses as well as linking the results from the different exposures. 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.

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

Number project reference group meetings held until report date:

We held a reference group meeting (2015-22/10).

Planned activities: (3-4 lines)

The activities have generated a large amount of samples and data so far. We will during the upcoming period analyse samples and link all the data from the different exposures. Two abstracts have been submitted to "Impacts of Fuel Quality on Power Production" conference which be held 19-23 September 2016 in Prague.

We will start to write the first stage report that will be submitted half way through the project (summer 2016).

Date
2016-03-31

Reporting period: 2015-10-01–2016-03-31

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

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 the planned work from last report. 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 has been started. Some interesting new results have been obtained addressing goals 4, 5 and 7.

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

We have started 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 4: We found that carbon atoms tend to partition into MX and form tantalum carbonitride ($\text{Ta}(\text{C},\text{N})$). The carbon concentration in the $\text{Ta}(\text{C},\text{N})$ particles decreases with the aging time, indicating the transformation into Z-phase (CrTaN). The transformation rate of these precipitates into Z-phase seems to be slower when the carbon concentration in the precipitates is higher. In addition, recently we found that if the C concentration is very low, CrN_2 precipitates are likely to form, which may lead to a new pathway for Z-phase formation.
2. For goal 5: The formation of detrimental BN primary particles is related to not only the B and N concentration, but also likely the C concentration.
3. For goal 7: Microstructure evolution of Laves phase formed in ZU1, ZU2 and ZU3 has been studied (This is 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:

Five meetings:

At Chalmers, August 28, 2014; present Lennart Johanson, Siemens; John Hald, DTU; and Masoud Rashidi, Fang Liu and Hans-Olof Andrén, Chalmers.

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.

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.

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.

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.

Planned activities: (3-4 lines)

We will continue to work on the formation and evolution of Laves-phase. Phase transformation to Z-phase in the steels will be analysed using XRD, which complements the microscopy techniques we have been using, and can give us global information.

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. Olivass (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 HVOF (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. Next outtake is planned for w18-20 2016. New samples, including model FeCrAl alloys, will be installed during this revision.

- 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 HVOF coated samples has been exposed as clamp materials.

For short term testing (up to one week), 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 will 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 effect of startup sequence of probe exposures were tested, analyzed 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 startup 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. The project manager has been in contact with these companies and the companies will come in with their in-kind contributions in soon time. 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.

Planned activities: (3-4 lines)

We plan to withdraw the second set of clamp samples from the boiler in week 18-20. At the same time, new clamp samples will be installed, primarily of FeCrAl model alloys.

We plan to do a probe (corrosion probes, in-situ alkali probe, in-situ corrosion probe, deposit probe) measurement campaign during the fall 2016. These exposures will be combined with thermodynamical calculations performed by Högskolan i Borås. In order to measure gaseous alkali chlorides in the flue gas, IACM is planned to be used.

Date

2016-04-04

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. Eklund (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:

Several projects meetings have been held during the start up process of the project. The activities regarding analysis of field samples and aging of materials have been initiated with a small delay due to awaiting the situation with Måbjergverket. Activities at Måbjergverket have now started with a delay since the plant has changed owners during the period. The project group put together an action plan in order to handle the situation and have informed the KME board during the process. An updated time plan has in addition been put together that will be sent to SEA, see attachment.

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

The project group has put together an updated time plan regarding the Sulfur recirculation part of the project, see attachment. The work at Måbjergværket has started:

- Component offers from sub-suppliers are currently being collected including instruments, H₂SO₄ pump and H₂O₂ storage tank. The SO₂ raw gas analyzer is currently being ordered. H₂O₂ and sulfuric acid piping is being engineered and planned.
- Project meeting 1 was held at Måbjergværket on 2016-02-03

The activities at DTU regarding analysis of field samples and aging of materials have been initiated.

Is time schedule and costs according to plan/budget? Comments over reasons if deviations: There has been a delay as described above. An updated budget is attached.

Number project reference group meetings held until report date:

A reference group meeting was held (2015-22/10).

Planned activities: (3-4 lines)

Startup of Sulfur Recirculation will preliminarily take place during week 35 in order to test the system and build up a sulfuric acid buffer in the scrubber system before the maintenance stop in September-October.

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.

Field samples have been collected. The samples have been exposed 17000 and 30000 hours. These materials will be analysed as planned. Aged material is available and will be exposed as planned.

Date
2015-03-31

Reporting period: 4Q 2015

Status report KME

Project title: Composite Metal Polymer for non-stick for improvements in CPH 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: As planned beside pending final signing of contract by Dong Energy. Samples installed at Öresundskraft cover the intended application components, if Dong will not attend the only negative project impact will be that we will only cover one type of fuel.

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-phosphate/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

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.

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-Kimba, 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)

- Evaluate Polymer candidates regarding wear resistance and non-stick properties in laboratory.
Following tests should be done for each candidate CMP material;
 - Evaluate non-stick "as-sprayed" by drop shape analysis
 - Evaluate non-stick after wear to "equilibrium" by drop shape analysis
 - Wear test to "equilibrium"
 - Microscope analysis of all candidates including penetration depth.
- Manufacture test samples for field installation at Dong Avedore plant during Christmas outage, as follows;
 - Economizer tube sample rack, candidates 2, 3, 4 and 8.
 - Low temperature superheater ½-tube, candidates 3, 4, 7 and 8.

- High temperature tube sample rack, candidates 4, 7, 9 and 10.
- Further investigation of the laboratory samples after the wear test, planned to be executed in May 2016;
 - Analysis of photos from the various time of wear test.
 - Non-stick "droplet" test of as-sprayed CMP
 - Non-stick "droplet" test of CMP after wear test.
- Take-out of first set of field samples at Öresundskraft, planned to be executed in May- June 2016;
 - Photos of each sample before removal of any possible slag.
 - Take-out one sample at each position, slag will not be removed, samples stored in plastic bags with de-moistening gel.
 - Manual evaluation of possible slag sticking force at locations for each position with no CMP.
 - D.o for CMP samples, Note! Don't remove all slag.
 - SEE (Systematic Electronic Evaluation) thickness readings by Elcometer on cleaned CMP surfaces.
 - Samples to Swerea-Kimab for analysis, Note! Sample preparation to be discussed before start.

Date
2016-04-17

Reporting period: 1st July 2015 – 31st Dec 2015

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 (0% activity during 2015 due to maternity leave)

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 has been started. Modelling of the test conditions has been started.

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: 0

Planned activities: (3-4 lines)

Combined project and reference group meeting 2nd June 2016.

Start of laboratory testing at Åbo Academy after the summer 2016.

Date
2016-04-04

Reporting period: Juli-December 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):

The PhD student started in November 2015. He is now fully engaged in the project. GKN acquired a large amount of cast Alloy 718 material which was heat treated, machined, and tested using Varestraint Weldability testing. These samples are now thoroughly being analysed by the student. The student presented some preliminary result at the international institute of welding (IIW) intermediate meeting in Madrid and will present the final result at the IIW annual meeting which later on will be submitted to a journal for review. The student is also working on a review paper on hot cracking of stainless steel which are of interest to the boiler industry. The review paper will be presented at the Swedish production symposium (SPS) in Lund now in October.

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:

One project meeting has been held with GKN. A second meeting together with AMEC is planned to be held at their site by mid-June.

Planned activities: (3-4 lines)

1. Finish the analyses of the Varestraint tested 718-samples
2. Finish the review paper which will be presented at the SPS-conference in Lund
3. visit to AMEC's site in Finland
4. Acquire stainless steel material
5. work on a new testing rationale for Gleeble testing and Varestraint weldability testing
 - a. make an upgrade of the Varestraint testing machine
6. Make a presentation at the Aerospace conference in Stockholm in October

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:

Since we have not yet received any samples from the boiler most of the project goals are yet to be fulfilled. The first set of samples are planned for after the summer revision.

However, 4 project meetings has been held and the planning of the upcoming exposures are proceeding according to plan.

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

No results so far, see above

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

Yes. The costs at Chalmers is however currently lower than the budget but this expected to be adjusted until the end of 2016 since more work is planned for the fall. Also, not all companies has reported their in-kind contribution to this date. The project manager is reminding these companies.

Number project reference group meetings held until report date:

One reference group meeting 22/10 2015 at Chalmers.

Planned activities: (3-4 lines)

We plan to withdraw the first set of clamp samples from the boiler in the summer of 2016 as well as installing new samples. Furthermore, during the revision a hole for the water wall probe will be arranged as well as building the probe. The short term probe testing campaign is planned for being executed during 2016. It will depend, primarily on the availability to use a alkali chloride monitor in the flue gas, whether this campaign will start in the spring or in the fall.