Quality management at RWE using T24 boiler material as an example

Ralf Nowack, Christoph Götte and Simon Heckmann

Introduction

European operators are currently being faced with the challenge of renewing their power plant networks to an as-yet unquantifiable degree. Thanks to efficiency gains, the new power plants will reduce CO₂ emissions and the use of specific fuels and, through additional measures applied in the cleaning of flue gases, significantly reduce emissions compared to those of the existing power plant network. If efficiency is to be raised in hard coal- and lignite-fired power plants, in particular, live steam and reheating temperatures need to be raised. This increase in temperature calls for the use of new materials in the production of steam, its piping, and in steam turbines.

After an almost 15-year period during which no new power plants have been constructed in Germany, current new-build projects place various needs on operators in respect of project and quality management. These needs are particularly related to the management of suppliers, quality controls applied to the manufacture and assembly of their products, and short expediting intervals during production. In addition, the implementation of professional claim management, against a background of increased risk due to international procurement, and the adoption of a more professional approach to supplier claim management, are urgently required.

Correspondingly, operator quality management calls for the implementation of a sustainable quality strategy, applied by an effective, learning organisation using customised processes.

This needs-oriented, project-specific, and yet integrated process management, creates a triad of project and quality management and engineering characterised by process efficiency, excellence and the optimised use of resources.

Only quality management structures set up to cope with the demands of major projects will be capable of dealing with challenges as they arise through proactive quality planning, assurance and controls (in the sense of a closed quality cycle).

RWE Technology’s approach involves employing its Quality Centre of Competence to the benefit of new-build projects and the RWE Group as a whole.

Use of T24

T24 was developed for use in the new generation of steam turbines. It is notable for its high creep rupture strength, compared to materials previously used. T24 is currently being used in 13 new-build hard coal- and lignite-fired power station projects in western Europe, including in Germany, the Netherlands and the Czech Republic. In these plants, it is used to line membrane pipe walls and heating surface banks, as well as for inner supporting pipes. The new-build projects in question are listed in Figure 1.

These plants have a total installed capacity of around 15 GW. RWE’s BoA 2&3 F and G lignite-fired units at Neurath and the hard coal-fired twin units at Westfalen D&E and Eemshaven A&B represent fully one-third of that capacity. The goal is to arrive at a fact-based analysis, so as to be able to take decisions that directly address the issues.

Qualification

To further increase the efficiency of hard coal-fired power plants to 46 % and lignite-fired plants to 43 %, new materials were required for the final superheating stages that would enable to achieve live steam temperatures of 600 °C. Suitable materials also needed to be developed for the initial superheater stages constructed as evaporator and membrane walls.

These materials would need to possess a higher yield strength at elevated temperatures and, in particular, higher creep rupture strength than the conventional membrane wall material.

At the same time, it was important that they could be worked with in the membrane wall as submerged arc-welded tube-fin joints, without requiring stress relief annealing. Materials such as 10CrMo9-10 or X10CrMoVNb9-1 (P91) were therefore out of the question.

In the mid-1990s an investigation of new materials as part of an AVIF research project, identifying T24, developed by Vallourec & Mannesmann, as the most promising material for use in membrane pipe walls.

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Specific studies included:
- FDBR/VGB research project “Qualification of materials for use in high-temperature steam generator plants” (A 77, period: 1994 to 1998)
- research project “A demonstration of the long-term properties of welded joints in modern steel for use in steam generators in temperatures up to 620 °C” (A 129, period: 1998 to 2001)

In addition to those investigations, the material was also used in trial projects such as EON’s Scholven power plant, as part of the Comtes 700 project, and in the EnBW plant at Altbach, as a test surface in membrane pipe walls.

In terms of T24, investigations centred on its welding qualities in respect of WIG and up welding, the corrosion performance of unannealed WIG weld seams and the tenacity and creep rupture behaviour of WIG weld seams. In addition to showing that the material’s welded seams were capable of fulfilling the requirements placed on the basic material in terms of thermal and creep strength stability, the investigations demonstrated that, thanks to its particular chemical composition, the material could be used even without post-weld heat treatment. For this to be the case, unannealed weld seams must be sufficiently ductile, thermally stable and not crack under welding.

At the time the investigations were carried out, it was already known that T24 requires more work if used in membrane walls than its predecessors, 16Mo3 and 13CrMo4-5. The suitability of T24 has now been established through VdTÜV material sheets and its technical supply conditions determined in DIN EN 10216, part 2, and the VGB Guideline VGB R 109, among others.

For the RWE-projects T24 was selected as the material suitable for use in diaphragm pipes. Occurrences of damage

In March 2010, substantial delays were experienced in commissioning Steag’s newly constructed Walsum 10 unit. Numerous leakages were detected in T24 circular weld seams following start-up.

High priority was assigned to the event by operators, leading to the first working meeting of VGB being called to address the issue of T24.

In August, the previously informal activities of the working group were coordinated by an operator steering committee (VGB LK T24) and three work groups were set up:
- Corrosion/treatment/hot commissioning
  Subject: material and damage mechanism
- Welding techniques/quality assurance/assembly tests (manufacture and assembly)
  Subject: manufacturing and testing
- Alternative cleaning methods
  Subject: chemical cleaning

Those working groups were to gain a more in-depth understanding of the damage mechanism and derive appropriate measures to prevent damage occurring. Independently of this, the operators themselves embarked upon their own investigations.

In October 2010, Vattenfall’s newly constructed Boxberg R steam turbine entered service. After only a few hundred hours of operation, however, it also had to be temporarily decommissioned, due to the appearance of numerous leaks.

Most recently, the recommissioning of the Walsum 10 plant, in April 2011, resulted in substantial damage being caused.

At that point in time, RWE’s projects were at various stages of completion.

While at the beginning of the situation in Walsum, the two BoA 2&2 units were mostly con-
The two plants (Walsum 10 and Boxberg R), in which damage events occurred during commissioning, are, on the one hand, switched differently and, on the other, use materials in a different way.

Different switching variants and material concepts are employed in the plants currently at the construction and commissioning stage. Two switching variants are mainly used:

- Variant A:
  - the evaporator begins at the entrance to the funnel and ends at the exit from the membrane-wall vertical piping.

- Variant B:
  - the evaporator begins at the entrance to the funnel and ends at the spiral pipe wall outlet. The membrane-wall vertical piping is employed as a first superheater.

In most projects, T24 is used in the final stage of the evaporator wall. In others, however, it is employed from the funnel entrance right through to the evaporator outlet. Furthermore, T24 is used in the first superheater and supporting tubes, as well as being frequently employed in the heating surface of the first reheater.

The two plants (Walsum 10 and Boxberg R), in which damage events occurred during commissioning, are, on the one hand, switched differently and, on the other, use materials in a different way.

Nearly all of the damage is located in the area employed as an evaporator through which water flows in a two-phase mixture. As yet, no reports have emerged from the damaged plants detailing damage to the support pipes or other heating surfaces caused by T24.

The different switching variants and most likely places for damage to occur are displayed in Figure 3.

Welds performed using T24, however, showed that it is indeed possible to employ a bainitic structure in the weld seam and heat affected zone. Precise adherence to the parameters of the processing instructions and no small skill on the part of the welder are required if the processing demands are to be met. Typical descriptions of seams currently being welded refer to them as “bainitic-martensitic”. Figure 4 depicts two of the resulting structures: a typical bainitic-martensitic weld metal structure and a structure welded with strict adherence to the parameters and which, like the base material, can be considered bainitic.

### Damage mechanism

In investigating the cause of damage at the Walsum 10 and Boxberg R plants, hydrogen-induced stress corrosion cracking (H-SCC) was identified as the mechanism.

Through interaction within a sensitive material state (e.g. a martensitic structure), hydrogen-induced stress corrosion can lead to the creation of critical stresses and the presence of a chemical corrosive agent (in this case, hydrogen). The preconditions for hydrogen-induced stress corrosion are shown in Figure 5.

Reports issued by the VGB task forces, among others, suggested that the damage always occurs at a weld seam and can present itself either parallel or perpendicular to the longitudinal axis of the tube. The crack may appear in the material in either a trans-crystalline or inter-crystalline form, beginning on the side in contact with the medium (inner pipe wall).

Many cracks appearing obliquely to the longitudinal axis of the tube begin in the root-side heat affected zone, running on a macroscopic scale.

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**Figures and Tables**

- Figure 3. Main switching variants and damage hot spots.
- Figure 4. Parameter window and possible weld metal structure variants.
RWE quality management exemplified at T24 boiler material

Investigation of causes

Investigations have been conducted by manufacturers and operators with the aim of both understanding the causes of the damage and identifying remedial measures that could be taken.

The three previously described factors were used as the starting points for investigation:
- Reduce the influence of the medium,
- Reduce the stresses, and
- Influence the structures.

Tests were conducted in different laboratories as to the influence of pickling in the casing of damage. The operators in question, manufacturers, VGB and RWE, through TÜV-Rheinland, conducted pickling tests. The aim of these tests was to investigate the effect of the different concentrations of fluoric acid-based pickling solutions, the role of the CL4 inhibitor and the H₂S connection found in reference samples. In addition, the investigations looked at the influence exerted by hydrogen on magnetite formation. Autoclave tests were carried out by VGB and the manufacturers and, at a later date, by others. The aim of these tests was to establish the conditions that lead to damage being caused and whether conditions could be identified that would prevent this.

One critical area in respect of the formation of hydrogen was identified as a temperature in the region of 200 °C. Within this range, an adverse combination of the formation of atomic hydrogen due to the Schikorr effect, increased uptake into the material and the reduced ability of the material to release H⁺-Ion is produced. In the trials, therefore, a temperature of higher than 300 °C was identified at which, given the reduced build-up of H⁺, the material could release H⁺-ions (soaking - hydrogen annealing). In addition, hydrogen formation is also influenced by pH values: higher pH values, for example, can substantially reduce maximum local hydrogen release levels.

In addition to preventing/reducing the effect of hydrogen, ways to reduce inner and outer stresses were also the subject of investigation. To reduce stress, two approaches have been identified:
- Heat treatment at low temperatures subsequent to assembly
- Low-temperature heat treatment is carried out to control the positioning of external stresses. RWE’s internal stress tests were undertaken beforehand at TÜV-Rheinland, using the borehole method. Stress measure-

As has already been mentioned, when the first damage occurred at Walsum, pressure part assembly on the BoA 2&3 project was largely stopped. The following measures were applied by the manufacturers for the project:
- Reducing external stresses through heat treatment of the boiler already constructed at 450 to 500 °C over a 24 to 48 hour period. The heating was performed using mobile oil burners located at various levels of the combustion chamber. These measures were accompanied by conversion of the flue gas outlet, to optimise heat treatment, and the installation of a flow of warm air in the entire pressure part, to even out thermal expansion between the heating surfaces and the connecting pipework.
- Optimised pickling To reduce the influence of pickling as a cause of damage, the T24 areas were omitted during pickling (approximately 25 % of the entire heating surface).
- Optimised water chemistry in the start-up process For this, a higher pH value was set and the O₂ content of the feedwater reduced to below 20 ppm. The feed water preparation was equipped with an external mobile water treatment with a hydrocine unit to be able to provide extremely low-oxygen water in sufficient quantities.
- Optimising the start-up procedure An increased temperature gradient was selected for start-up. The gradient was maintained until a steam temperature at the...
Avoid the damage-including medium (hydrogen)
- Optimised chemical cleaning (pickling)
- Optimised water chemistry of boiler water
- Optimised start-up procedure

Sensitivity material condition
- Avoid critical stresses
  - Heat treatment at 450 to 500 °C following completion

Critical stresses
- Triggering medium
- Avoid the damage-including medium (hydrogen)
- Optimised start-up procedure

Figure 7. Measures applied in the BoA 2&3 project.

Evaporator outlet of > 300 °C was achieved. This temperature was maintained over a longer period. The measures were backed up with the aid of an auxiliary steam generator so that, should the burner suffer an interruption, the minimum temperature could be maintained for a certain period by feeding in auxiliary steam.

Experience to date using this approach has proved positive, however, it remains to be seen how the plant will perform under full-capacity operating conditions. The measures applied in the BoA 2&3 project are summarised in Figure 7.

Conclusions

From RWE’s point of view, based on learnings gained from current commissioning and the investigations carried out, the following conclusions can be drawn:

- T24 is suitable for use in membrane pipe walls. Project-specific requirements and the detailed boiler design must be taken into account.
- Particular attention needs to be paid to:
  - Welding parameters,
  - Welder qualification, manual dexterity, and 
  - The supervision of welding work
- Even in plants already completed, risks can be reduced through the subsequent application of suitable measures.
- For components currently under construction, strict adherence to the guidelines and greater emphasis on quality assurance can significantly reduce the risk of errors occurring during processing.
- Intensive investigations are underway through VGB to determine the extent to which further measures applied in the heat treatment of welded seams may further reduce the associated risks.

Summary and outlook

The lessons learned from the BoA 2&3 project are used as the basis for measures applied during follow-up projects and, together with other learnings, can provide the basis for future projects. Essentially, this lesson-learning process represents an important supporting pillar in RWE’s approach to quality management, across all its projects. Key to success will be – as it always is – ensuring that all organisational, process-related and technical measures are closely coordinated with each other.

Effect chains for future RWE projects are displayed in Figure 8.

An analogue application of the measures applied in the BoA 2&3 project and the application of further measures by the manufacturers is planned for the Westfalen and Eemshaven hard coal-fired projects.

In the first instance, welders will be trained by the suppliers specifically in the use of T24 in manufacture and assembly, to ensure the strict application of welding guidelines.

RWE will be stepping up its supervision of manufacture and assembly activities, to allow adherence to the welding guidelines to be more strictly controlled.

Stress-relieved annealing of the joints between spiral and vertical tubing will enable the stress levels in these components to be reduced and their structural properties improved.

At the beginning of commissioning, the measures already applied in the BoA 2&3 project to reduce stresses through heat treatment at 450 to 500 °C and reduce the levels of hydrogen are to be reapplied.

It has been shown that RWE Technology has the resources and expertise to deal with the quality problems arising in connection with boiler material T24 over the long term, and to ensure the required sharing of knowledge between the different projects. Thus, RWE Technology is in the position, to react immediately with expertise in key positions to quality problems in the projects.

Working closely with project and engineering management, measures have been successfully introduced which have led to a reduction in the risk associated with the described quality problems in current projects.

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