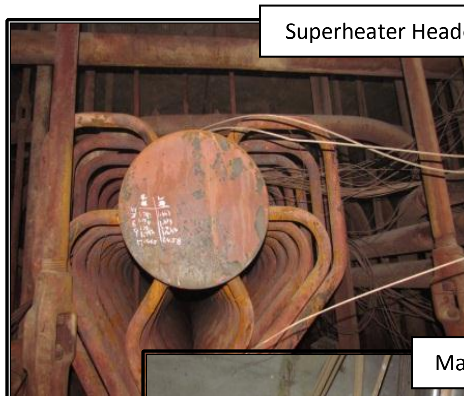
TECHNICAL REPORT

Grade 91: Is it passing the test?

The use of modified 9-Cr (Grade 91) steel in modern power plants is derived from the unique properties of the material in comparison to carbon steels or lower chrome materials. Assets such as superior creep and tensile strength characteristics allow for the use of thinner materials in the design and manufacturing of piping systems and pressure vessels. These are desirable characteristics in terms of thermal cycling, hence the wide spread use of the material in newer combined cycle plants.



Grade 91 is commonly used in superheater components (ie. MS, HRH, SHOH, RHOH) which are very susceptible to thermal fatigue due to high temperatures and frequent cycling. Thinner walled components allow for smaller temperature gradients across their pressure boundaries and thus reach thermal equilibrium faster, which fights thermal fatigue damage.

For a typical superheater header, an upgrade from the traditional P22 alloy to P91 can provide the following:

- Reduce wall thickness by nearly two-thirds and component weight by 60%
- Raise allowable strength in the 950^{o}F-1100^{o}F range by up to 150%
- Raise the oxidation limit by 100^{o}F, enabling a lower corrosion allowance
- Increase thermal-fatigue life by a factor of 10 to 12

Unfortunately, since the use of Grade 91 began in the UK in the late 1980's many complications associated with this particular material have been revealed over its relatively short lifetime. Grade 91 materials provide significant field welding challenges in terms of backing, preheat, and post weld heat treat programs. There is little margin for error when welding and/or heat treating this material. With increased knowledge of these issues, Thielsch Engineering, Inc. has worked with various clients throughout the country to educate on the use of this material and how to rectify problems caused by its improper usage.

Unlike carbon and low alloy steels, the elevated creep strength in 9-Cr material depends on achieving and maintaining a specific microstructure. This specific microstructure is created by the transformation to martensite, which is achieved during the cooling process. Any event during manufacture, erection, or operation that disrupts this microstructure will compromise the integrity of the material and prevent it from achieving the creep properties upon which the applicable code allowable stresses are based.

Recent industry experience has identified another adverse property of the material which has resulted in plant failures. Softening of the material cause by a low Nitrogen to Aluminum ratio of approximately <2.0 has been identified as a condition that leads to a loss of Vanadium due to Al-N precipitation. This results in lower creep strength and can initiate type IV cracking of the material.


Grade P91 Cracking

Grade P91 materials have properties that differ from traditional low-alloy materials and thus should be handled differently than other low-alloyed steels. Our experience of working closely with P91 has indicated that purchasers, manufacturers, constructors, and plant owners are mishandling the material and therefore damaging the microstructure. Damage to this microstructure may lead to a rapid increase in failures, which should not occur prematurely.


Grade T91 Cracking

Regular occurrences in component fabrication, plant construction, and steam plant repairs have been found to damage the microstructure. These processes include: hot bending, forging, and welding. Degradation may not be detectable by standard QA tests, but extensive inspection techniques provided by Thielsch Engineering experts to include metallurgical testing can increase the ability to identify possible microstructural abnormalities.


TEI personnel performing metallurgical replications

As part of Thielsch Engineering's metallurgical evaluations, both in-situ metallographic examinations (replications) and/or boat samples may be utilized. These evaluations are performed in order to identify any microstructural changes that may have occurred in the material. In either case, they are examined comprehensively by optical microscopy at magnifications of 100X to 500X. This will provide information about the microstructural condition of the boat samples and identify any service-related deterioration that they may have experienced. Photomicrographs are taken to document the typical conditions observed in the replica foils.

Laboratory boat sample removed from circumferential girth weld

The microstructures are compared with the creep classification developed by EPRI. In addition to this type of testing, boat samples are also analyzed quantitatively by Optical Emission Spectroscopy to determine the chemical composition of the base and weld materials. Finally, boat samples are subjected to stress-rupture testing. It combines the variables of temperature and time to rupture into a single value that can then be used to assess the creep strength of a given sample by comparison with standard curves developed for the particular material of which the sample is composed.

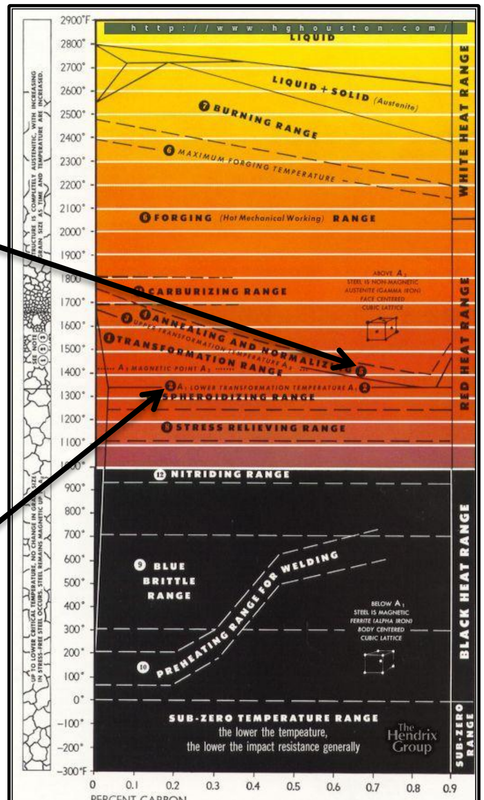
One recent case study identified the sensitivity of the Grade 91 microstructure at two combined-cycle plants in the Southeast. The owner detected several locations, in both bends and straight pipe, where material specified to be P91 was actually in the over-tempered condition rather than in the optimal tempered martensitic condition. In the over-tempered condition, this 9-Cr material will exhibit a substantially higher creep rate at the plant's operating temperature of 1050F, and a much lower hardness value (<180 on the Vickers Hardness scale or HV, instead of the expected 200+ HV).

Significantly, this unacceptable material condition was discovered, not through the standard QA procedures conducted by the pipe fabricators or plant constructors, but only by special metallurgical replication ordered by a very concerned and vigilant owner. Subsequent investigation revealed that the post-bending tempering procedure had caused these sections of piping to cool far too slowly, with the inevitable result that the structure was over-tempered. Symptomatic of the industry's "business-as-usual" nonchalance toward Grade 91, the heat-treatment procedure used by the plants' contractor was similar to the one they had used for decades with P22.

ASME has recently created a task group assigned to research and establish more rigorous rules for the thermal processing of Grade 91 as well as the other four "creep-strength-enhanced ferritic alloys" (asme.com).

The pending current code change recommendations are as follows:

- Normalizing: in a tightly defined temperature range of 1900^{o}F -1975^{o}F. The minimum temperature limit for normalizing will be established to ensure complete resolution of the most temper resistant of the precipitates, while the maximum temperature limit will be imposed to minimize detrimental grain coarsening.
- Tempering: in a tightly defined temperature range of 1350^{o}F -1470^{o}F. The minimum temperature limit for tempering will be established to ensure that sufficient precipitation is induced to stabilize the structure, and that a reasonable level of ductility is imparted to the material. The maximum temperature limit will be established to minimize the risk of the reduction in rupture strength that can occur when heating above Ac_1 [lower transformation temperature].
- If any component fabricated from Grade 91 is "locally" heated above 1470^{o}F, then either the entire component must be re-normalized and tempered, or the heated section must be removed from the component in its entirety, re-normalized and tempered, and then re-inserted into the component by whatever means is appropriate.



Map provided by Tempil, makers of temperature indicating devices

The repeated failures and notable issues have formulated a possible industry wide trend which suggests that more documentation and proper protocols will be implemented during the construction of components fabricated from Grade 91 material. An inclination of more rigorous inspections is evident and should be implemented for all areas of concern. Proper record keeping providing all necessary information on the handling of this material during the manufacturing and fabrication processes may drastically reduce the area requiring metallurgical inspections, however, if proper documentation has not been kept there can be no way to tell if proper procedures have been followed. Thielsch Engineering, Inc. offers its clients the support that is needed to accurately identify, evaluate, and recommend solutions to reduce unwarranted and costly failures.

Thielsch Engineering, Inc. hosts over 30 years of advanced engineering experience and provides extensive services to more than 150 power plants each year. We are an employee owned company with over 425 partners who are dedicated to best practices and customer service is a priority. Thielsch has offices in Rhode Island, Ohio, Texas and our newest location is in Boca Raton, FL. We serve clients across the country and internationally. Each location is fully staffed with experienced engineers and technicians that are highly skilled professionals prepared to handle any routine or complex engineering project.

Thielsch specializes in boiler and high energy piping systems and offers full laboratory services. Our teams are available for planned and emergency outages and work diligently to ensure each project is completed on time and with the highest level of expertise and professionalism. To discuss our experience working with P91 please contact Peter Kennefick at pkennefick@thielsch.com or by phone at (401) 467-6454.