The P92 Review

A Review of Metallurgy, Fabrication, Welding, Failure, Application, Integrity and Remaining Life Assessment Issues

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Foreword

This review deals with the status and use of the modern high strength steel P92. This is the first review conducted by ETD solely on P92 although three previous reviews in martensitic steels that included P92 were conducted in the years 2000, 2006 and 2011. These reviews were sponsored by international industry from Europe, USA, Canada, Middle East and Asia. The first review had looked at the use of mainly 9Cr martensitic steels, the findings from research and limited plant experience available at that time. The second review, in addition to the above, covered other high strength steels for high temperature application and some of the new developments in the important aspect of integrity and life assessment of these steels. The third review covered the welding, weld consumables, weld repair, cracking and failures, component integrity and life assessment and, in addition, the developments in NDE techniques for the early stage creep cavitation and damage detection in components made from P91 type steel. This fourth review focuses on P92 as its use in the last 10 years has dramatically increased.

One of the most frequent causes for problems with P91 was a general lack of knowledge and experience of the basic metallurgy of this high-alloy steel which requires much greater understanding than the low alloy steels (such as T22) for successful use. Therefore this review gives an overview of the metallurgy of P92 in the belief that an improved understanding of the metallurgy among manufacturers and users will lead to more successful use.

With increased use of P92, and following on from some of the difficulties experienced with its predecessor P91, interest in integrity/life assessment and monitoring of these components is acute. This is especially so because the traditional NDE methods of replication and early stage damage detection in these steels have been found to be less than satisfactory and therefore there has been a need to develop, study and establish new methodologies and techniques for life assessment of these steels. A number of new developments in this area (including those recently explored and developed by ETD led teams) have been reviewed and more promising techniques highlighted. The study has brought together research and plant experience in the area of integrity and life assessment from Japan, Europe and North America to throw light on potentially successful techniques that should be adopted.

The welding and heat treatment of the 9Cr martensitic steels, including P92, is critical in that small deviations from ideal practices can result in devastating consequences. In this era of competition, manufacturers and service providers are keen to save costs and therefore may look for lower cost sub-contractors for component fabrication and welding. However, some of these sub-contractors may not always be aware of the criticality of welding and heat treatment of these steels and incidents are known where this has resulted in problems with plant even before their full fledged operation. Similarly choosing a welding process and welding consumables also requires the knowledge of what is available and the effect of these on the performance of P92 steel components. This issue has therefore been dealt with in detail in this report and guidance provided.

Dissimilar metal welds are always a problem area in high temperature plant due to, amongst others, different heat treatment requirements for the two adjoining metals. In the case of the high Cr martensitic steels this situation becomes even more demanding and this has been discussed in this report.

As the service life of the predecessor P91 reaches the mid-life stage and the material shows signs of cracking and failure, it is important to learn lessons from the issues involved with weld repairs and explore how these can be applied to P92. This aspect has been researched particularly in Europe and is discussed in this review.

The issue of steam-side oxidation has proved to be problematic for T91, and this would also be expected for T92. The consequences of this in terms of tube life, damage to turbine blades etc. have been discussed in this report together with the alternatives available. This has been preceded by the science of various types of oxides that form on these steels and their behaviour and effect on the rise in metal temperature.

It is important to understand the process of creep strengthening in the new high strength steels and how their strength is affected by actual material chemical composition within the standards' specification, fabrication and exposure at high temperatures and pressures. Therefore, this review discusses the microstructural details of these steels and their behaviour and integrity under creep and creep-fatigue (particularly for cycling plant) conditions. The current evaluations indicate that steel P92 is approximately 25-30% stronger than steel P91 at temperatures higher than 575°C.

Much research has been going on P92 steel for the past ten years or so and much has been published, so it is important to synthesise this in to a useful and user-friendly document which can be easily followed by plant engineers without getting lost in the details of the research itself. It was also important to bring together research findings and plant experience so that a comprehensive and comprehensible document can be provided which relates to plant experience and works as a guide for plant manufacturers, service providers and plant operators.

Contents

Figures List

Tables List

Introduction

Due to the price competition associated with privatization coupled with environmental requirements there has been a quest for higher output and more efficient ultra supercritical power plant operating at higher temperatures and pressures. Steels with better creep resistance are therefore required.

For existing steam plant that may operate in cycling mode high resistance to thermal fatigue is also required. Here high strength steels offer an additional benefit. The reduced section thickness increases pipework flexibility and reduces the level of through-wall temperature gradients in thick-section components. Because of this envisaged benefit a number of operators/owners of the existing plant are substituting these new higher strength steels for the older materials, especially when a plant is moved from base load to cyclic operation. The use of new higher strength steels also has benefits for the manufacturers as the transportation, erection, welding and such other costs are decreased for thinner section components made from these steels. There has also been a perceived advantage of higher steam-side oxidation resistance of superheater tubes made from high Cr steels. For the Heat Recovery Steam Generators (HRSGs) used in Combined Cycle Gas Turbines (CCGTs) there is a requirement to produce compact size units and thus high strength steels are used to make smaller size components.

The 9Cr martensitic steels were developed as a result of the above demand for higher strength more creep-resistant alloys but to date while there has been limited in-plant experience of the long-term performance of P91 there is much less for P92, especially with thick section components such as headers and steam pipework. However, judging from earlier experience with lower grade ferritic alloys and experience with P91 material, the long-term performance of components fabricated from P92 martensitic steel needs careful observation. There have, to date, been some surprising reports of premature failures of P91 weldments in plant but as usual the causes of such failures have been complex. Due to the similarities between P91 and P92 some of the lessons learned from use of the former may beapplied to the use of the latter and this will be discussed throughout this review. Nevertheless, one has to guard against the possibility that the situation for weldments could become more critical when plant reaches longer life in particular for the plant operating in cyclic mode. It follows from this that there may also be a need to weld repair P92 equipment which has been in service for a comparatively long period. Microstructures of weldments and parent materials being repaired will be in an aged condition and this brings problems of its own in terms of best practice and life prediction. There is also still a problem with life prediction of the high alloy martensitic steels. In the lower alloy steels, cavitation and deterioration of microscopically observable microstructure (spheroidisation etc.) can be used to predict at least qualitatively the remaining life. Creep cavitation occurs late in the life of high Cr martensitic steels and therefore cannot be used to predict life and take remedial measures until it is too late. Therefore, new techniques have to be developed to predict integrity at the mid-life stage and undertake repair or replace decisions.

There are also issues with welding during construction. The high Cr martensitic steels could be vulnerable to stress corrosion cracking if post weld heat treatment is not carried out soon after welding and the material is left in a moist atmosphere for some time. The same appears to be true for pipe bends if left for long periods without post bend heat treatment. Other issues involve the criticality of the heat treatment of both the base metal and the weldments as over-tempering and under-tempering are both known to be harmful.

There is also the issue of the varying codes dealing with these steels. Some of the information provided there is deemed to be unsatisfactory and indeed new ASME committees of experts are now reviewing the codes in light of operating and manufacturing experience. Nevertheless at the international level new plants are being made to these codes with consequences that can be unpleasant both from an economic and safety viewpoint. The other problem is the welding (the control of which is critical for the performance of these steels) by sub-contractors from companies and regions with lower costs but in some cases also lower skill and knowledge levels. This factor is known to have played a role in the failure of some of the components made from these steels.

There is also a discussion about the effect of chemical composition and the alloying elements on the performance of these steels such that some compositions within the specified limits are considered more vulnerable than others, both in terms of creep strength and steam-side oxidation.

New information is coming out on a regular basis throwing light on the behaviour of these steels and this will be discussed in this report.

Study Methodology

The objective of this study was to review the research and plant experience and to study implications for plant using P92 steels as new or replacement materials. This study was conducted as follows:

- Published and unpublished (through private contacts) information from a number of Japanese, European, North American and other potential contacts was accessed and analysed.

- Important players in this field such as plant operators, manufacturers, service providers, and researchers were interviewed by visiting, where necessary, or interviewing them in conferences and thus a dossier of experience was built up.

- Information on inspection strategies such as hardness tests, checks on heat treatment records, microstructure, NDE strategies adopted by the plant users, etc was collected and reviewed.

- Available information on work funded by individual organisations, national bodies, European Commission, European Pressure Equipment Research Council's work and the European Creep Collaborative Committees' projects 'Weld Creep' and 'Advanced Creep' etc. and any information that became available from NIMS (Japan) etc. was analysed and reviewed.

- Various aspects of the use of these steels were studied and special emphasis was placed on the behaviour of welds when operating under creep, creep/fatigue conditions and performance in steam, i.e. steam-side oxidation.

International Standards and Codes for P92

Throughout this report, reference will be made to the various standards that cover P92. As this report draws on experience and data from around the world it is important to briefly summarise the codes, where they originate and other potential names that P92 can go by; this is done in Table 0-1.

Table 0-1 Some of the key International Standards and Codes for P92

Specification and grade	Country	Description
EN 10216-2 Grade X10CrWMoVNb9-2	Europe	Seamless steel tubes for pressure purposes – technical delivery conditions Part 2: Non alloy and alloy steel tubes with specified elevated temperature properties
VdTUV WB 552/2 Grade X10CrWMoVNb9-2	Germany	High temperature steel
KA-STBA29	Japan	These grades are introduced in the Ministry of Economy, Trade and Industry (METI) Thermal Power Standard Code
KA-STPA29		
ASTM A 213 Grade T92 (ASME SA-213)	USA	Seamless, ferritic and austenitic alloy-steel boiler, superheater and heat-exchanger tubes
ASTM A 335 Grade P92 (ASME SA-335)		Seamless ferritic alloy-steel pipe for high-temperature service
ASTM A 182 Grade F92		Forged or rolled alloy and stainless steel pipe flanges, forged fittings, and valves and parts for high-temperature service
ASTM A 369 FP92		Carbon and ferritic alloy-steel forged and bored pipe for high-temperature service