Materials and Data Review

A Review of Martensitic 9-12% Chromium Steels for Elevated Temperature Service

(*Acronym*: **Materials & Data Review**)

Final Report

ETD Report No: 1089-gsp-113

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ETD Report No: 1089-gsp-113

ETD Project No: 1089-gsp-proj07

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Executive Summary

This review of martensitic 9-12% chromium steels for elevated temperature service is the final report for one of the four sub-projects of ETD's "Materials & Data Review" (ETD project no. 1089-gsp-proj07). The other three sub-projects provide reviews of (i) low alloy ferritic steels, (ii) austenitic stainless steels (including super stainless steels), and (iii) nickel-based alloys for use in new and modern steam plants.

This Report is also a follow up to the earlier series of reports on martensitic 9-12% chromium steels, the first of which was produced in 2002 and the second in 2006. Since the 2nd report ETD has been involved in a number of consultancy jobs where it has been called upon by both plant manufacturers and plant operators to help and assist in problems such as issues involved with new welds in plant being manufactured/ erected where welds have shown unsuspected incidences of cracking or where welded components in operating plants have exhibited either cracking or shown other suspect features on inspection or monitoring. ETD is also being continuously asked to help with the guidance in the quality checks of new P91 and P92 materials supply and with the inspection and monitoring of components in plant to ensure their integrity. In addition, ETD has been involved in: a) the development of new and more sensitive and reliable inspection and life assessment techniques for this new class of materials, b) conducting training courses and workshops in London, USA and elsewhere involving industry engineers from around the world, and, c) running an international P91 Users Group. It is through this experience and background and involvement in a number of research findings and international conferences and meetings on the subject that this report has been compiled and issues concerning 9-12 Cr martensitic steels critically reviewed here. ***This report is twice the size of the 2006 report and this shows the significance of the new additions.***

Since the issue of the 2006 report, many advances have taken place in the development of life assessment techniques for this class of steels which have shown enormous problems in the detection of early stage creep damage due to the nano size of creep cavities that cannot be detected by the traditional replication or UT techniques. Thus new ***inspection techniques*** developing and using a portable Scanning Force Microscope for early stage damage detection and experiments with the new developments in the UT and potential drop techniques have been explored and further developed and these are described in this report. These can be further explored and developed by the readers of this report or they can contact ETD at: enquiries@etd-consulting.com for advice, guidance and support, if necessary.

Similarly, with regards to the ***life assessment*** of P91, P92 components, many developments have taken place, studies have been conducted in Europe, Japan and elsewhere and some of these have been practised in real plant situations. These developments have been critically reviewed here and explained for the benefit of the plant operators where P91, P92 components may have operated for a while.

Many plants have reported problems with the use of T91 for reheater and superheater tubing, especially with ***steam side oxidation*** issues. In cases this has led to early replacement of T91 tubing with alternative materials resulting in a great deal of expense both in terms of material and labour cost and lost production. *Aluminium coating* and *chemical cleaning* have been/ are being explored to overcome this issue and again some of the results have been very encouraging and have resulted in commercial or near commercial exploitation of such techniques. These issues have been discussed or reported in this review. Plant operators using such tubes need to know the appropriate time when to replace these tubes if this becomes necessary as too early a replacement can result in unnecessary loss of revenue. This means that appropriate tube life assessment techniques are required to reliably predict the *remaining life* of such components. This is an area where ETD is working together with its colleagues from Japan and these issues have been discussed in this report. Armed with this knowledge a plant operator in future should be able to reliably decide to replace any such tubes during the next major planned outage thus saving loss of production costs due to the unplanned outages.

In the earlier reports (2002 and 2006), a number of ***incidents of cracking*** and failure had been reported in P91 thick-section welded components in the UK, Europe and North America. Most of these had occurred in the Type IV position and some in dissimilar metal welds. Since then hundreds of incidents of cracking have been reported worldwide and a couple have also been reported in the base metal adding to the worries of the plant operators. Such incidents have been discussed in this report.

In the earlier reports (2002 and 2006), the ***use of P91 and P92 in thin and thick section components in plant worldwide*** had been tabulated as a general guidance. Since then this use has become widespread and especially in heat recovery steam generators (HRSGs) the use of P91 comes as a standard. Thus it is not possible anymore to list all the plants using P91. However, the old list of the original plant has been reproduced here to give an indication of the temperatures and pressures at which these steels are currently being used.

Earlier reports had discussed the performance of welded components and their behaviour in plant but not ***weld consumables and their properties***. This report has discussed this issue in some length with evaluation of different available weld consumables and the choice of welding procedures and their appropriateness under different circumstances.

The failure in Japan of a P122 hot reheat pipe some years ago and subsequent attribution of this to the ***Z phase*** in this 12Cr steel came as a blow to both the Japanese steels producers who had invested heavily in the development of this steel and the manufacturers of new plants who were aiming for higher temperatures and pressures. It also dampened the hope that 12Cr steel could be used for superheater and reheater tubing due to its higher resistance to steam oxidation. This aspect is covered in some detail in this report.

Type IV cracking which has bedevilled the low alloys in high temperature industry for over half a century now has become an even bigger problem for the 9-12Cr steels. Although there is not much of a cure for the steels already in use except appropriate inspection, monitoring and maintenance, NIMS in Japan, and to a lesser extent European researchers, have been looking at the idea of ***adding Boron to eliminate the problem of Type IV cracking*** in high Cr steels and this is looking very promising indeed. Steel producers in Japan are already producing demonstration casts and the hope is that this should overcome the major problem of Type IV cracking in these and other steels for use in high temperature industry.

Last but not least, one of the most important aspects of this report is the ***datasheets for 9-12 Cr steels*** which have been produced here in detail, about 36 pages in all. These cover both the physical and mechanical property data from various standards, codes and international bodies such as the European Creep Collaborative Committee (ECCC). These have been critically reviewed and contrasted and the differences between them discussed. These should be of particular use to both the plant manufacturers and operators and help them with the evaluation of the plant life.

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APPENDICES

Management Overview

This review deals with the status and use of modern high strength steels (in particular P91, P92, E911 and P122). This is the third review of its kind; the first two were conducted in the years 2000 and 2006. Both reviews were sponsored by international industry from Europe, USA, Canada, Japan, Middle East, South Asia, Far East and South Africa. 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. This third review covers 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.

Some years ago ***failures*** in P91 components were still relatively new and were attributed to weak or suspect casts. A host of new failures worldwide have occurred since then and therefore interest in integrity/life assessment and monitoring of these components has become 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 was 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 many of these steels 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 the start of their 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 the 9-12Cr 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 other issues, 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 together with the actual experience to date.

As the service life of P91 reaches the mid-life stage and the material shows signs of cracking and failure, it is important to understand the issues involved with ***weld repairs***. This aspect has been researched particularly in Europe and is discussed in this review.

More recently, new light has been thrown on the ***steam-side oxidation*** and this has proved to be not so good for steels, especially for superheaters, with less than about 11%Cr. 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 ***microstructure*** details of these steels and their behaviour and integrity under creep and creep-fatigue (particularly for cycling plant) conditions.

Finally, it is important for the plant owners and operators to know important ***inspection and quality control*** criteria *when buying plants and components made from these steels*. Here we have interviewed plant operators with the most successful experience and the report provides guidance on what to ask for and look for when buying new plant or replacement components.

So much research has been going on these steels for the past ten years or so and so much has been published that it was 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 easily comprehensible document can be provided which relates to plant experience and works as a guide for plant manufacturers, service providers and plant operators.
