Materials and Data Review

A Review of Austenitic Stainless Steels for Elevated Temperature Service

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

Final Report

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Executive Summary

This review of austenitic stainless 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) martensitic 9-12% chromium steels, and (iii) nickel-based alloys.

This report has reviewed published literature, international standards and codes, reports from research programmes, and experience from actual service, to present a comprehensive catalogue of information on the metallurgical development, properties, application and service performance of the austenitic stainless steels. The focus of the review is the grades used for high temperature pipework and superheaters in power plant. Both the traditional Type 300 series grades and more recently developed, higher strength alloys are discussed. The material property values have been collated in some detail, mainly from product standards published in Europe, and design standards/codes from the USA and Japan. Data from the different standards/codes have been compared.

Although in some countries there is a reasonable understanding of these materials, because of their cost and perceived shortcomings, there has been a tendency to limit steam temperatures and pressures in an effort to avoid the use of the austenitic stainless steels. Because of rising fuel costs, this is becoming less feasible and it does seem that new plants will have to make considerable use of the austenitic steels.

Times have moved on, and our knowledge about the performance and behaviour of the stainless steels is greatly improved. Much better creep data are now available for the older types of austenitic steel. In some cases creep rupture predictions extend out to 250,000 hours. More importantly, a number of manufacturers have developed stronger and more corrosion-resistant alloys. Hence, this report endeavours to review the most recent published information on creep properties and to highlight alloy developments. The review will indicate why it is that the more recent materials are stronger and have improved oxidation resistance.

Much of this report also deals with a comparison of creep rupture data from European, USA and Japanese sources. The information is available in two different types. Firstly, the European Creep Collaborative Committee (ECCC) and European (EN) standards provide stress rupture data, in which the 100,000 hour stress rupture strength values have been estimated. The other type of data is based on the design strengths as given in the ASME and Japanese (METI) pressure vessel codes. In this case, the design strengths at the lower temperatures are based on the short time proof or tensile stress. At the higher temperatures, the design strengths are based on the 100,000 hour stress rupture strength values, in which a factor of 2/3 is used to derive the basic design strength values. Accordingly in making the comparison with the stress rupture values given in the ECCC Data Sheets and/or EN standards, the design stress values in the creep range of the ASME and METI codes are multiplied by a factor of 1.5.

All of the stress rupture values coming from these different sources are tabulated and compared in this review. This comparison of the data will be useful to engineers when they are considering more advanced designs of power plant which will require superheater systems to operate at higher temperatures and pressures. In some cases, because of problems with existing stainless

steel components, replacements are having to be considered, and ideally these replacements should be better than the existing components. Hence, important questions are:

- **When should stainless steels be considered for use in more advanced plant?**
- **In what ways are they superior to lower alloy ferritic type steels?**
- **What types of stainless steel are available?**
- **How do the older and newer types of stainless steel compare?**
- **What is the experience of user organisations?**

As already noted, it is generally agreed that the high temperature austenitic steels have drawbacks. One of the most important is that their thermal conductivity values are lower and their coefficients of thermal expansion are higher than those of the ferritic steels. These characteristics result in stainless steel components suffering from more severe thermal fatigue during plant temperature changes, and the thermal fatigue issue was a major factor in halting the advance to higher temperatures and pressures.

A major aim of this report is to give a balanced view of the potential of the more advanced austenitic stainless steels, most of which have originated in Japan. One method of making this assessment was to examine the estimates of stress rupture strength issued by the various authorities. The broad conclusions of the comparisons is that there is no reason to think that there are serious overestimates in the design strengths, if any exist at all. It follows from this that for the designer has access to materials which are significantly better in strength terms than the standard alloys. Fortunately for the new materials, the relative improvement compared to Type 316 increases with increasing temperature. This is a result of using more stable precipitates which begin to form at temperatures above 600ºC.

Fireside and steam-side corrosion do become at least as significant an issue as that of creep at temperatures in excess of 550ºC. In older plants, where the 18/8 austenitics were used, in which the chromium levels were insufficient to protect against corrosion, Type 310 or even Alloy 671 were used as cladding. Alloys such as Type 347HFG are unlikely to have better corrosion resistance than the conventional 18/8 steels, but preliminary work indicates that the higher chromium advanced alloys such as NF709 and HR3C may be adequate in some cases and might be considered for use without claddings. Caution needs to be exercised on this point. The rate of fireside corrosion is dependent on both the type of coal being used, the design of the furnace and superheater and reheater arrangements.

In terms of steam-side corrosion, the development of the fine grained version of Type 347 is proving a success in reducing oxidation rates, and preventing scale exfoliation. For other materials of a similar chromium content it seems advisable to shot peen steam pipe internals.

The long-term performance of welds is also a major consideration in the development of advanced plant. Various authorities are postulating weld efficiency factors from 0.63 through to 0.9. One reason for the poor performance of matching welds is that they are likely to form sigma phase after long-term exposure. The strength of welds is reduced as a result, but weld ductility is also likely to suffer. Hence complex welded components may experience problems if subject to plant cycling after a long period of trouble-free operation under base load conditions. More creep testing of weldments is a priority, and more work is needed on the issue of reheat cracking.

The other area where more research is needed is that of transition welds. In the new plant, the most likely combination is stainless steel pipework welded to P91 or P92 ferritic/martensitic steels. Welds of this type have been in service for several years or more, without any reports of failures having been published. In the longer-term, when such plants are subject to two-shift operation, it is possible that the repeated cycles of thermal stress due to differential expansion of the austenitic and the ferritic materials could give concern.

A balanced view of the use of the advanced alloys is that there is every reason to use them in low supercritical applications where steam temperatures are in the 580-600ºC range, implying metal temperatures up to about 640ºC and steam pressures below 300 bar. Given the tendency of the standard austenitics to suffer from scale spallation because of steam-side oxidation, a reasonable decision is to use Type 347HFG which, even though it is not the strongest of the newer materials, it will allow 30% reduction in wall thickness.

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