Materials and Data Review

A Review of Ni-Based Alloys for Elevated Temperature Service

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

Final Report

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Executive Summary

This review of nickel-based alloys 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) austenitic stainless steels.

Considerable research and development activities are underway worldwide with the aim of increasing steam temperatures of power plant boilers and turbines to 700ºC and even higher. The higher steam temperatures will mean a shift to constructional materials of higher strength than the steels which have been used in the past.

Initially, the scope of this review of nickel-based alloys was focused on those alloys being considered as 'candidate materials' for application in the boilers and turbines of the advanced '700°C' class of steam power plant. All of the nickel-based alloys under consideration for advanced steam plant are commercially available alloys. Of course, these materials were originally developed for gas turbine applications, which is another area of interest to some of the project sponsors. In accordance with priorities identified by the project sponsors, this report also covers other nickel-based alloys that are of interest to users of gas turbines, but are not necessarily required for advanced steam power plant. The following alloys are considered:

Alloy X	Alloy X-750
Alloy 230	Rene 41
Alloy 617	Alloy 625
Alloy 80A	Alloy 718
Alloy 706	Udimet 520
Alloy W	Udimet 720
Alloy 263	Waspaloy
Alloy 282	Alloy 713
Alloy 90	Alloy 738
Alloy 740	GTD-111
Alloy 105	Alloy 186LC
Alloy 115	Alloy 247LC
	Alloy SX-4

This report has reviewed published literature, manufacturers' data sheets, and reports from research programmes to present a comprehensive catalogue of information on the metallurgical development, properties and performance of the nickel-based alloys.

The review begins with a description of the historical metallurgical development of the nickel-based alloys, both precipitation hardened and solid solution strengthened materials. The candidate materials for the critical components of advanced steam power plant are identified, and the testing programmes carried out on these alloys in Europe and elsewhere are discussed. The physical and mechanical properties of these alloys are

presented and reviewed, and the steam oxidation resistance and fabrication issues are discussed, including post-weld stress relaxation cracking.

The report includes (i) a collection of *Data Sheets* for the major alloys covered by the report and (ii) example microstructures of selected alloys in various conditions (e.g. as-received or service-exposed). The Data Sheets were compiled using data obtained from manufacturers' data sheets, and also from the ASME code (where applicable). Thus, the report provides a comprehensive catalogue of information and data on the nickel-based alloys and their properties.

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1. INTRODUCTION

Initially, the scope of this review of nickel-based alloys was focused on those alloys being considered as 'candidate materials' for application in the boilers and turbines of the advanced '700°C' class of steam power plant. In accordance with priorities identified by the project sponsors, this review also covers other nickel-based alloys that are of interest to users of gas turbines, but are not necessarily required for advanced steam power plant.

In the development of power generation plant, there is the requirement for increased efficiency, thereby reducing fuel consumption and lowering the emissions. Considerable research and development activities are underway worldwide with the aim of increasing steam temperatures to 700ºC and even higher. The higher process temperatures will mean a shift to constructional materials of higher strength than the steels (ferritic, bainitic, martensitic, austenitic) which have been used in the past. In this review, the properties of alloys that could be considered for these higher steam temperatures are described. Many of them are well-established nickel-based alloys that were originally developed for aero gas turbines. There are also some newer alloys that have been developed during the last 10 years or so, specifically to meet the requirements of advanced power plant. The amount of data for these alloys is not as extensive as that available for the older alloys, but is sufficient for a limited comparison of likely service behaviour.

The properties considered in this report are:

- physical properties
- tensile strength and ductility
- creep and stress rupture strength
- fatigue properties
- corrosion
- fabrication issues, including welding

The principal property that guides the selection of alloys *for advanced power plant* is the creep rupture strength. A useful criterion is that a mean 100 000 h stress rupture strength of 100 MPa is required. Figure 1 shows the maximum temperature of service operation for the nickel alloys covered in this review, based on this criterion. Comparison values for ferritic/martensitic steels and austenitic steels are also shown. For the newer alloys (marked with asterisks) in the diagram, the 100 000 h stress rupture strength values have been extrapolated from relatively short-term data (1000 – 10,000 h). The details of the alloys and the significance of this diagram will be discussed in Section 5 of the report. For the moment, it is clear that for plant operating at temperatures of 700°C and above, nickel-base alloys will have to be used for the components operating at the highest temperatures. Accordingly there have been many projects carried out in recent years to investigate the nickel-base alloys, many of which were developed for service temperatures higher, and sometimes considerably higher, than 700°C.

The nickel-base alloys under consideration are all commercially available alloys. The designations depend on the manufacturer, for example INCONEL and NIMONIC are trade names of the Special Metals Corporation (formerly the INCO group) and may only be used for products from this manufacturer. Similarly Nicrofer refers to alloys manufactured by Krupp-VDM, and Hastelloy is a trade name of Haynes International Inc. (formerly Haynes Stellite). In

this report, simpler designations will be used, so that for instance INCONEL alloy 617 (Nicrofer 5520 Co) will be designated Alloy 617, and Hastelloy X (INCONEL alloy HX) will be designated Alloy X.