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Section 7: Appendix

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The efficiency of pulverized coal power plants is a strong function of the steam temperature and pressure. Research to increase both has been pursued worldwide since the energy crisis in the 1970s. The need to reduce CO₂ emission has recently provided an additional incentive to increase efficiency of power plants. Thus, steam temperatures of the most efficient fossil power plants are now in the 600 °C (1112 °F) range, representing an increase of about 60 °C (108 °F) in the last 30 years. Nearly two dozen plants have been commissioned worldwide, with main steam temperatures of 580 to 600 °C (1080 to 1112 °F) and pressures of 24 to 30 MPa (3400 to 4200 psi). It is expected that steam temperatures will rise another 50 to 100 °C (90 to 180 °F) in the next 30 years. The main enabling technology for the increase plant efficiency is the development of stronger high temperature materials. Worldwide research has resulted in numerous high strength alloys for heavy section piping, tubing, waterwalls, and steam turbine rotors.

For heavy-section components such as pipes and headers, minimizing thermal fatigue has been a major driver in addition to achieving high creep strength. For this reason, alloy development has focused on ferritic steels containing 9-12%Cr. Optimization of C, Nb, Mo, and V, and partial substitution of W for Mo in the 9-12%Cr ferritic steels has resulted in three new alloys HCM12A, NF616, and E911 (P122, P92, and E911), capable of operating up to 620 °C (1150 °F) at steam pressures up to 35 MPa (5000 psi). Beyond 620 °C (1150 °F), oxidation resistance may become an additional limiting factor, especially for the 9% containing steels. A newer class of 12%Cr alloys, NF12 and SAVE12, containing Co and additional W, is being evaluated for possible 650 °C (1200 °F) application. For higher temperatures, transition will need to be made to nickel-base alloys such as 617 modified 617, 230, 263, 740, and others. Austenitic steels would be avoided for heavy section applications to eliminate the thermal fatigue problem. In addition to creep and thermal fatigue, other property requirements include steamside oxidation resistance, fracture toughness, weldability, and fabricability.

For superheater/reheater tubes, steamside oxidation resistance and fireside corrosion resistance are major drivers, in addition to creep resistance. Furthermore, tube metal temperatures often exceed the steam temperature by as much as 50 °C (90 °F). It is unlikely that any ferritic steels can be used in the finishing stages of SH/RH circuits at metal temperatures exceeding 620 °C (1150 °F). Austenitic steels need to be used at these high temperatures up to about 675 °C (1250 °F). Candidate alloys include super 304H, 347 HFG, SAVE25, Sanicro 25, HR3C, NF709, CR 30A, HR6W, and a few others. Depending on the corrosivity of the coal used, high chromium steels or clad or coated steels may be required. For even higher temperatures Nickel-base alloys mentioned earlier are being considered.

For upper waterwall sections in the boiler, two new steels containing 2.5Cr, known as HCM2 (T23) and 7CrMoVTiB1010 (T24) and a 12%Cr steel HCM12, respectively, are very promising in terms of creep strength and weldability. They are suitable for use up to metal temperature of 565 °C (1050 °F) purely from a creep-strength point of view. When fireside corrosion in low NOₓ boilers is an issue, these alloys will have to be clad or weld overlaid with alloys containing more than 25%Cr.

For HP/IP steam turbine rotors, several alloys, TMK1, TR1100, TOS107, and a modified GE alloy, can operate up to 593 °C (1100 °F). Some European alloys and Japanese alloys (TOS110, EPDC alloy B) have been tested as trial rotors and can be used up to 620 °C. For 650 °C (1200 °F) application alloys, HR1200 and a European alloy designated Fn5 seem to be
promising candidates, but have not yet been fully qualified. The alloy development here follows a path similar to that of boiler steels and stepwise development consisting of addition of Mo, V, Nb, or N2 of W at the expense of Mo, increases W and addition of Co and sometimes boron. A low Al, low Ni modified version of HR1200 also seems promising. For high temperatures, Ni-based alloys have to be considered. Ni-base alloys/ferritic steel welded rotor construction is also being investigated in order to minimize the use of the expensive nickel.

In summary, the materials technology needed to construct ultra supercritical plants with steam temperatures up to 620 °C (1150 °F) and pressure up to 35 MPa (5000 psi) is mostly available, largely in the form of commercial steels. It is anticipated that the capability to operate at 650 °C can be achieved in the very near future. A European consortium partially funded by the European Union under the “Thermie” program, is developing materials technology aimed at an efficiency close to 45% HHV. This will require steam temperatures up to 700 °C (1300 °F) which, in turn, gives rise to the need for higher strength ferritic steels (that do not need post-welding heat treatment) for waterwalls, and higher-strength stainless steels and nickel-base superalloys for the pressure parts that handle the highest-temperature steam. In the US, the Department of Energy and the Ohio Coal Development Office (OCDO) are funding a consortium of boiler manufacturers, utilities, national labs and universities to develop materials for even higher temperatures. Similar efforts have been underway in Japan.

These are indeed exciting times for the materials community. EPRI has been holding an international conference on Advanced Materials Technology for Fossil Power Plants every three years. The previous conferences were held in London, San Sebastian, Spain and Swansea, U.K. in 1995, 1998, and 2001, respectively. This conference is the fourth in the series. Based on the program, it is obvious that the most current developments have been captured in the proceedings. We want to express our sincere thanks to the 180 delegates representing 20 countries, who made this conference a success. Special note should be made of the following contributions:

- Session chairmen, authors and delegates for guaranteeing the scientific quality
- Co-sponsorship provided by USDOE, OCDO and ASM
- Panel members
- Members of the organizing committee and international liaison committee
- The organizational skills and administrative talents of the Conference Secretariat, in particular, Brent Lancaster and Jane Faust
- ASM International (ASM) for publishing this book

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