HIGH CREEP-STRENGTH ALLOYS

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INTRODUCTION

Alloys with high creep strength at 650-750°C are essential for new, highly efficient, ultrasupercritical (USC) steam power plants [1-3]. While such alloys for boiler application must also be construction-code approved materials which resist both creep deformation and the severe fire-side corrosion environment, those constraints are relaxed somewhat for USC steam turbines [4]. This effort highlights and summarizes some of the latest work going on at ORNL to characterize and develop alloys with significantly better creep-resistance relative to standard, commercially available materials in the alloy classes of martensitic/ferritic steels, austenitic stainless steels and nickel-based superalloys. One fundamental premis here is that better properties performance is achieved by careful control of alloy composition and processing conditions to produce materials that develop appropriate and stable microstructures for prolonged high-temperature creep-strength and rupture resistance. This paper highlights the following: a.) wrought and cast lean austenitic stainless steels based on modifications of type 347 stainless steel (cast grade is CF8C); b.) bainitic 3Cr and martensitic 9Cr steels with modified compositions and processing; and c.) collaboration with Special Metals on processing to improve the creep-resistance of the new 740 alloy, which is stronger than alloy 617. The steels and stainless steels are most relevant to turbine casing or steam supply hardware applications, while the alloy 740 originally designed for superheater tubing and headers may also be applicable to turbine bolting or blading component applications.

DISCUSSION OF CURRENT ACTIVITIES

WROUGHT AND CAST AUSTENITIC STAINLESS STEELS

Wrought stainless steels have been developed at ORNL for better creep rupture strength at 700-750°C. Using the "engineered microstructures" approach, these alloys are designed to have stable nano-scale carbide dispersions within the grains for strength without the coarse intermetallic phases (i.e., Laves or sigma) that cause embrittlement. Modified steels based on type 347 stainless steel, but containing judicious additions of Mn, N and other elements, have been developed as foils for other applications [5],

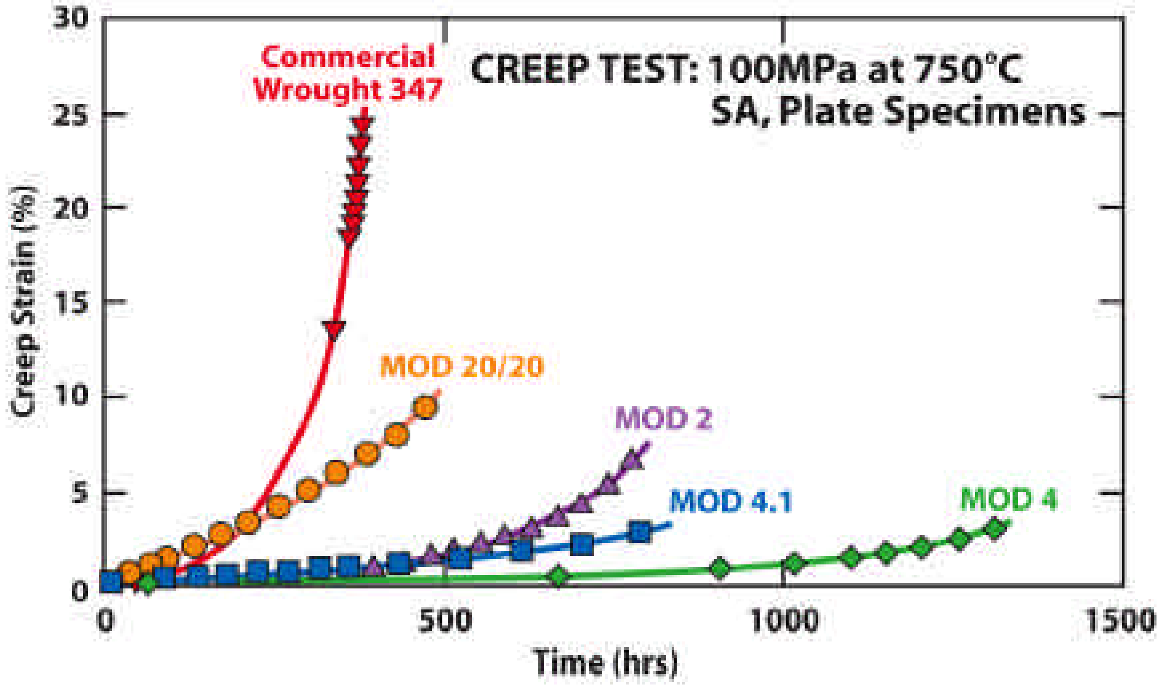

Figure 1 – Creep curves of annealed plate specimens of commercial 347 stainless steel and lab-scale heats of ORNL developmental alloys, including a Fe-20Cr-20Ni alloy and several modified 347 steels.

but have been creep tested here as thicker plate at 750°C and 100 MPa. Creep-rupture test results are shown in Fig. 1. Clearly, the modified 347-4 and 347-4.1 steels show significantly better creep resistance than standard, commercial 347 stainless steel at 750°C.

ORNL has also been working with Caterpillar for the last several years to developed a modified CF8C cast stainless steel with better creep-rupture resistance at 700-850°C, for heavy-duty truck diesel exhaust component applications [6]. Cast CF8C steel is similar to wrought 347 steel. The modified version, CF8C-Plus, also has additions of Mn and N and was designed to have an "engineered microstructure" for better creep, fatigue, thermal fatigue and aging resistance relative to the standard steel. The new cast CF8C-Plus stainless steel has significantly better creep-rupture strength than standard CF8C steel for testing at 700-800°C, as shown in Fig. 2. This material is a candidate for turbine casings with better heat-resistance and temperature capability than standard bainitic or martensitic steels used for steam- or combustion gas-turbines today.

If the new ORNL modified 347 steel or the new cast CF8C-Plus steel is compared to the best developmental or commercial austenitic stainless steels and alloys available world-wide, they appear to be comparable to NF709 developed by Nippon Steel in Japan and better than either Esshete 1250 steel or the European Union (EU) modified (Cr, N, Cu and W) versions of that steel (Fig. 3) [3]. The CF8C-Plus steel appears to have a clear advantage above 700°C over the other steels and alloys.

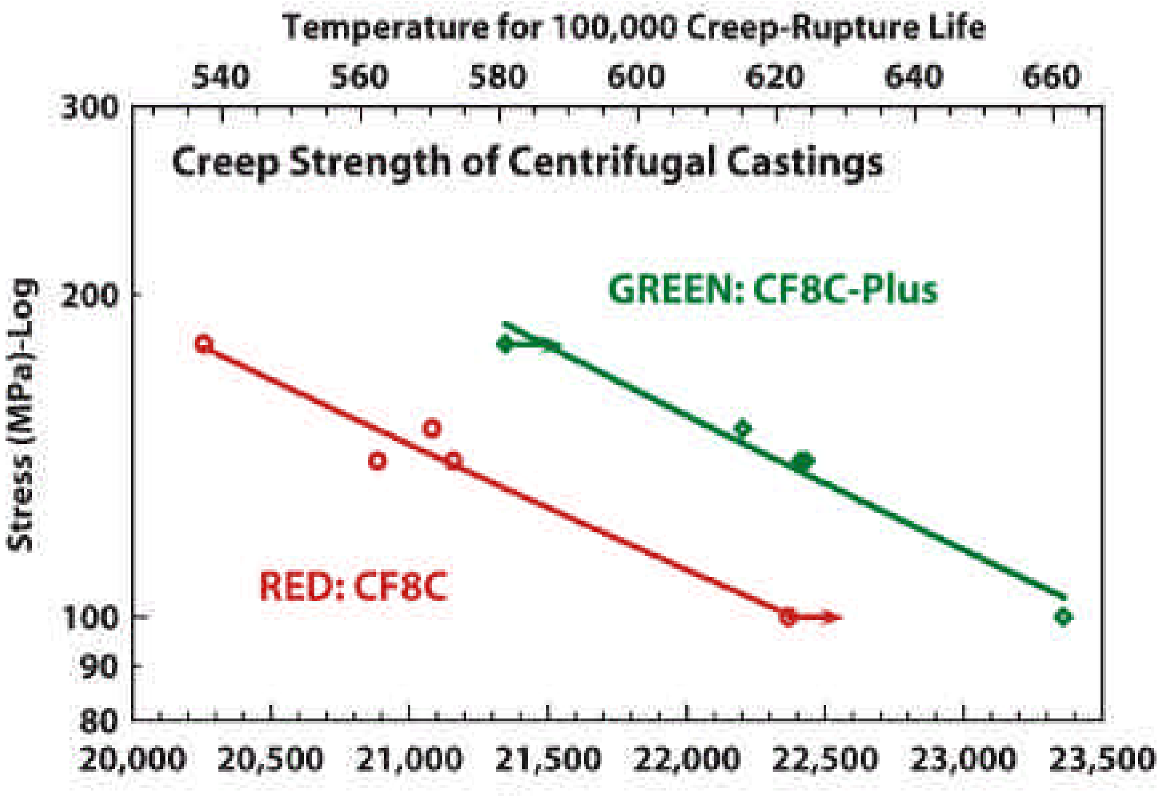

Figure 2 – Comparison of commercial centrifugal castings of standard CF8C and the new CF8C-Plus cast austenitic stainless steels creep rupture tested in air at 700-800°C. The upper axis is an extrapolation of shorter term data to temperatures that would allow the material to have a 100,000 h rupture life at the given stress level.

WROUGHT BAINITIC AND MARTENSITIC STEELS

While there has been considerable work over the last several decades aimed at improving the high-temperature strength and use temperatures of bainitic and martensitic steels [1-4,7,8], recent work at ORNL has produced new 3Cr-3WV and 3Cr-3WVTa bainitic steels and new 9Cr steels with much better strength at 550-700°C [9-12]. Again, as found for the austenitic stainless steels describe above, the improved high temperature strength is directly attributable to unique, nanoscale carbide or other phase structures that are very resistant to dissolution or coarsening. Creep properties of the bainitic steels are shown in Fig. 4, and properties of the new 9 Cr steels are shown in Fig. 5. In both cases, there is a processing benefit, in that both types of steels show even higher strength in the untempered condition. The strength of the untempered 9Cr steels is comparable to the very high strength of oxide-dispersion-strengthened (ODS) alloys, which is extraordinary.

NEW WROUGHT INCONEL@ 740 ALLOY

INCONEL@ 740 alloy is a new Ni- and Co-based superalloy developed by Special Metals to have high creep resistance and fire-side corrosion resistance in ultra-supercritical (USC) boiler conditions at 700°C and above [1,2]. This new alloy is also one of the candidate alloys being studied by the U.S. USC Boiler Consortium for steam temperatures approaching or exceeding 760°C [2,13]. It may also be applicable to some of the components in the corresponding USC steam turbine program [4]. Work at ORNL examined processing variables for alloy 740, and showed the obvious benefits of higher solution-annealing temperatures on creep-rupture resistance, as shown for creep-testing at 816°C in air in Fig. 6. As with the other classes of materials, microcharacterization work at ORNL has shown that improvements in creep resistance are related to clear changes in microstructural evolution caused by the difference in heat-treatment conditions.

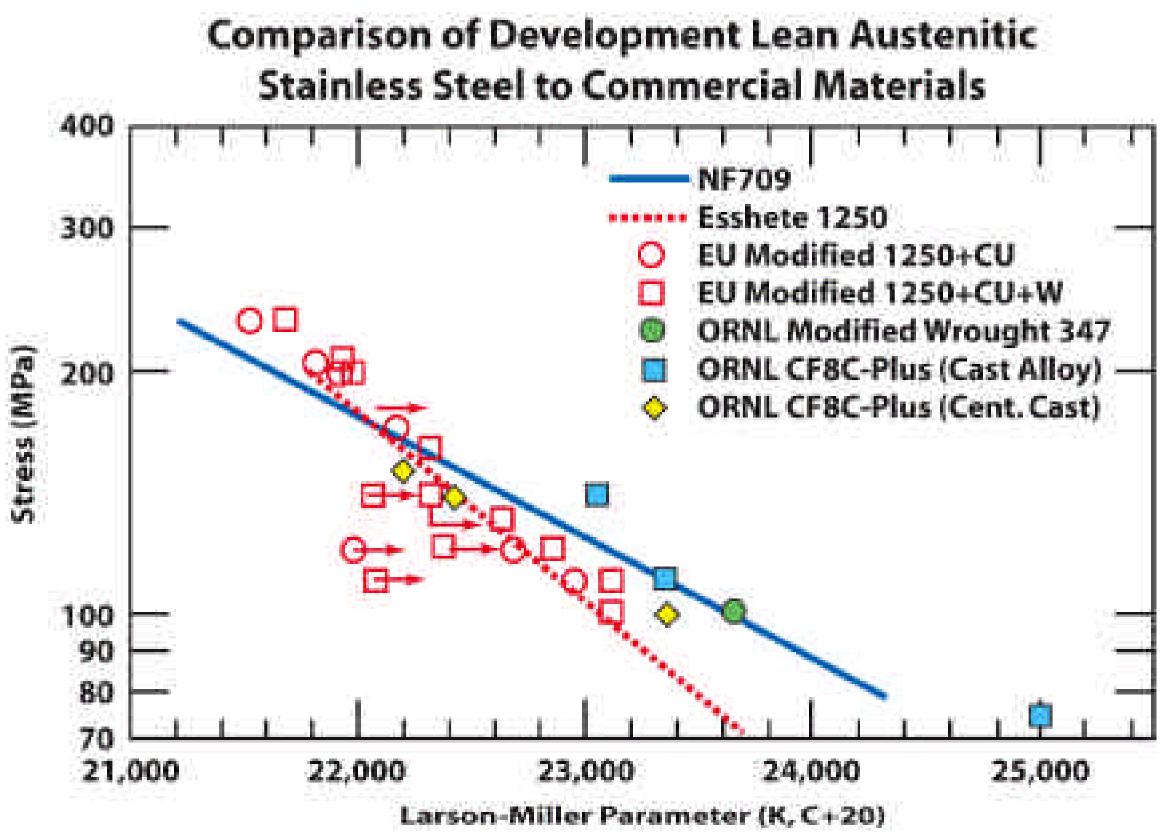

Figure – 3 Plots of Larson-Miller Parameter (LMP) versus test stress for new wrought ORNL modified 347 steels and cast CF8C-Plus steel together with comparable creep data on European developmental steels to improve on Esshete 1250 or the NF709 (Fe-20Cr-25Ni-Nb,N) stainless alloy developed in Japan. The new ORNL steels compare well with NF709, which is one of the strongest stainless alloys.

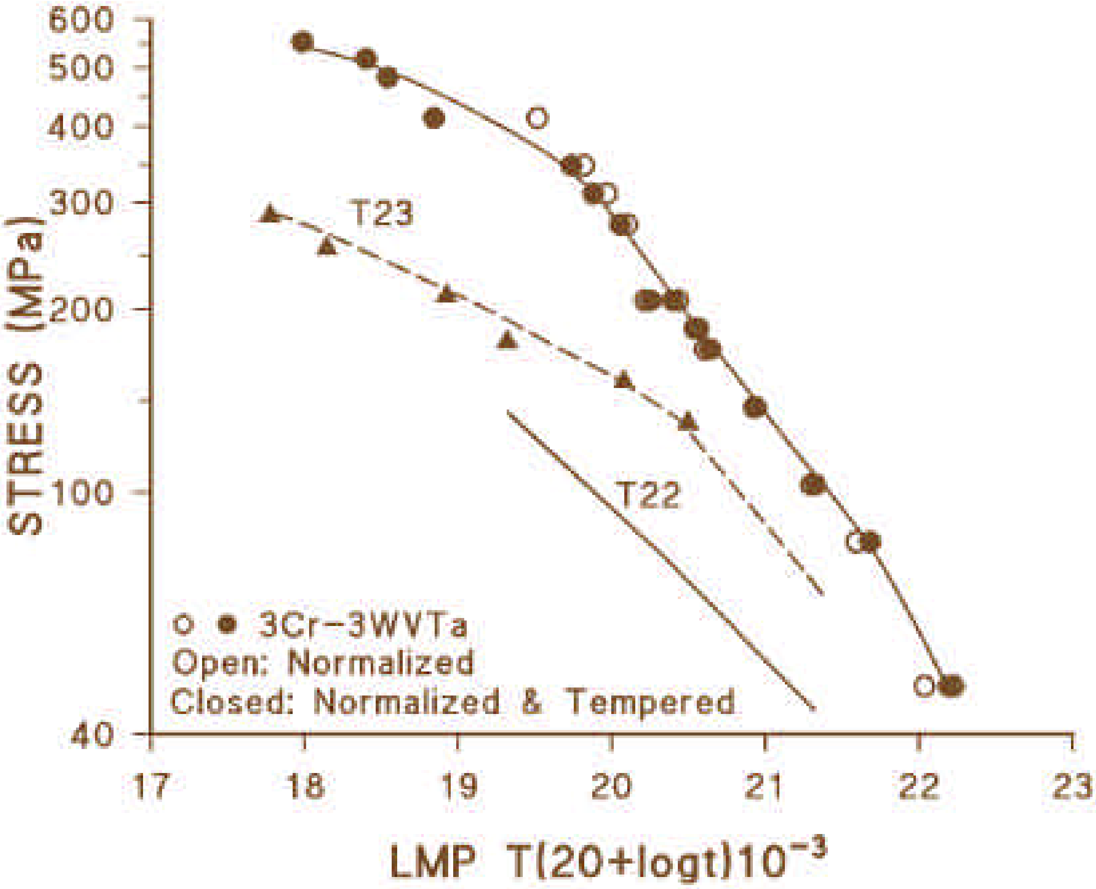

Figure 4 – A plot of Larson-Miller Parameter (LMP) versus stress for creep data on the new wrought ORNL 3Cr-3WVTa bainitic steel developed recently, with commercial bainitic steels T22 and T23 for comparison. The new ORNL steel has significantly better creep-strength when tested at 550-650°C.

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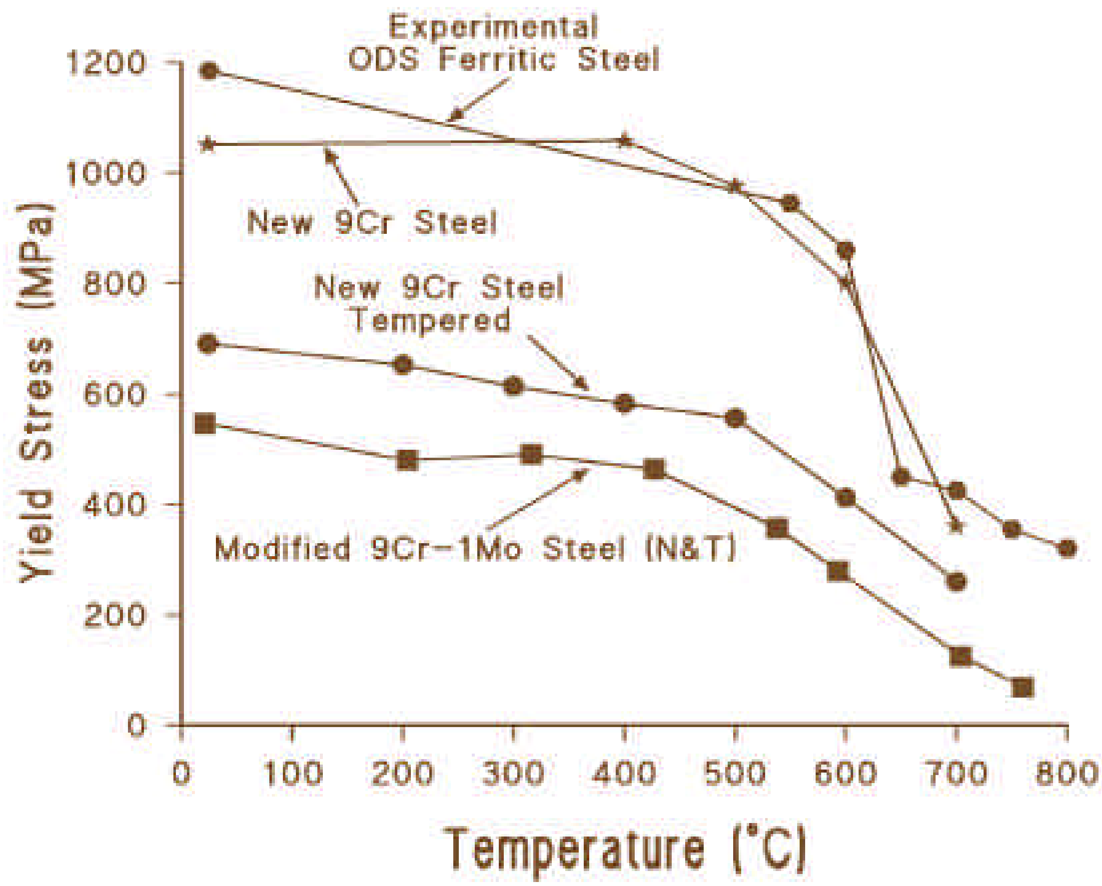

Figure 5 – Comparison of yield strength versus test temperature for new ORNL 9Cr steel which has significantly better strength than standard normalized and tempered 9Cr-1Mo-VNb steel, but is as strong as an ODS Fe-14Cr steel in the untempered condition.

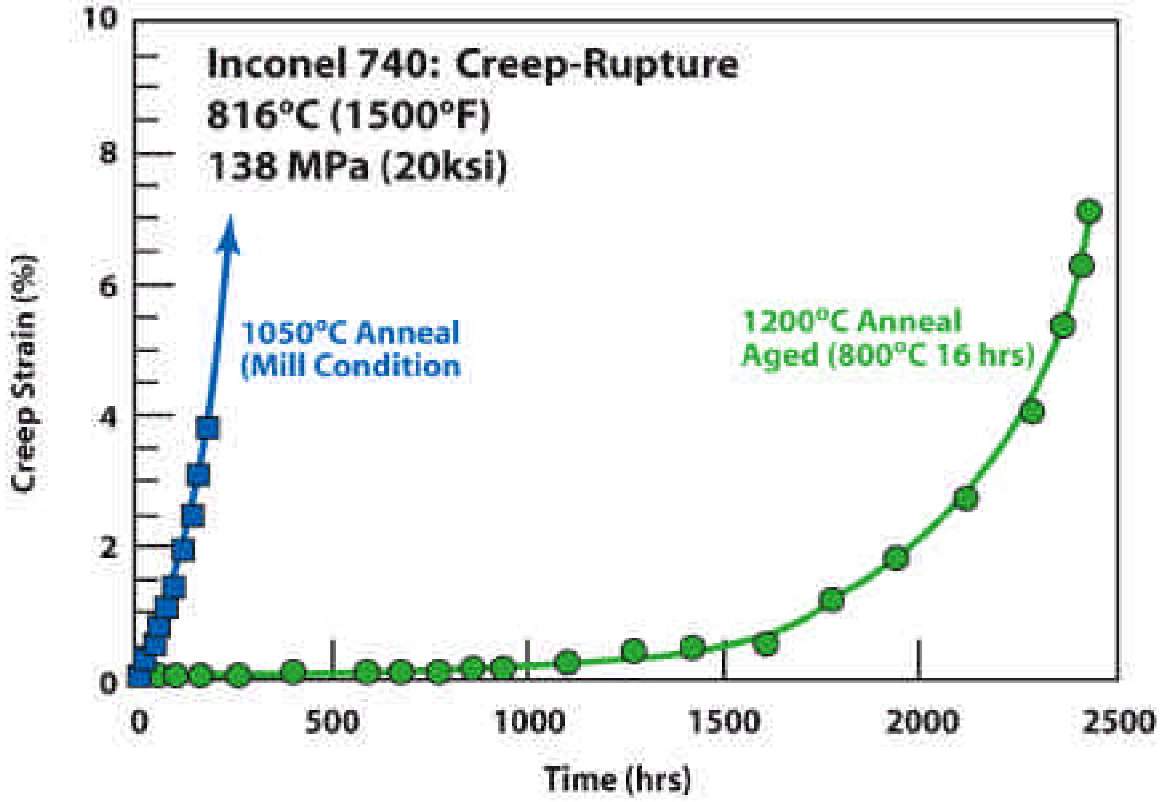

Figure 6 – Comparison of creep strain versus time for specimens of new Inconel 740 (Ni-Cr-Co alloy) tested with different solution-annealing temperatures.