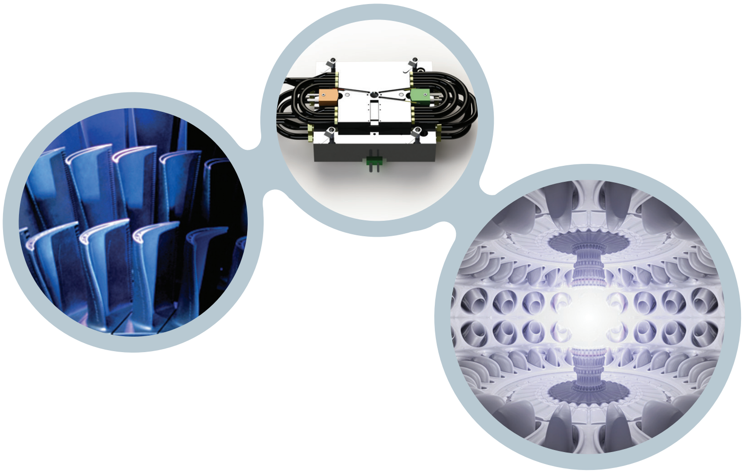

Application Note #1515

Oxide Dispersion Strengthened Steel Tested up to 700°C

Oxide dispersion strengthened (ODS) alloys are materials with very high creep resistance at elevated temperatures. Due to their excellent mechanical properties in such extreme conditions, they are often used for various demanding applications in such important industrial areas as energy production, turbine blades, or heat exchanger tubing. An ODS FeCrAl alloy, containing oxides of YAlO perovskite (YAP), $Y_2Al_5O_{12}$ garnet (YAG) and $Y_4Al_2O_9$ monoclinic (YAM), was investigated [1]. The strengthening mechanism of the investigated ODS alloy is related to the grain size of ~1 μm and the presence of dispersed oxide particles (~10 nm to 30 nm) that control the grain growth at elevated temperatures. Accordingly, the motion of dislocations is locked at the interfaces between the particle and the matrix, which translates into higher yield stress. However, this mechanism is only effective up to 60% of the melting temperature for the ODS alloy, as at higher temperatures the initial diffusion of voids allows the dislocations to climb around the oxide particles, causing the ODS strengthening mechanism to be ineffective.

Procedure

Mechanical characterization of the ODS alloy at elevated temperatures was performed with the xSol® High-Temperature Stage integrated into the Hysitron® TI 950 TriboIndenter®. A sapphire Berkovich indenter was used for the nanoindentation and creep experiments. Oxidation at the elevated temperature was prevented through the use of shield gas, a blend of hydrogen (5%) and nitrogen (95%). The tight temperature control of the xSol and the controlled environment provided stable testing conditions.

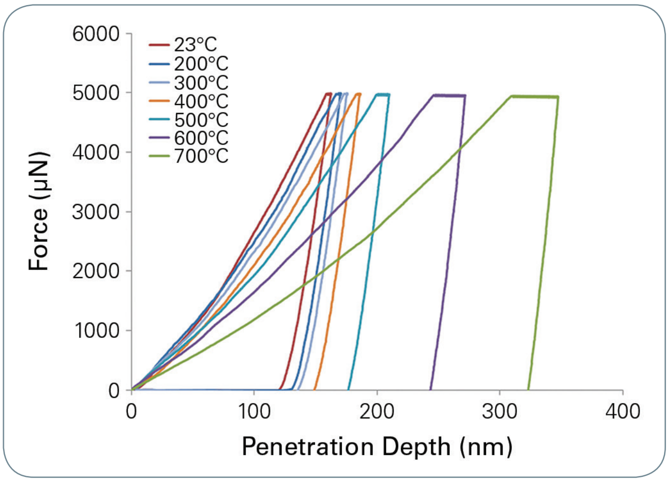

Figure 1. Force-displacement indentation curves obtained for temperatures up to 700°C from the quasi-static indentation performed with 10s of loading, 5s of hold, and 1s unloading.

Results

The force-displacement curves from quasi-static indentation (Figure 1) exhibit regular behavior and increasing plasticity with the increase in temperature. At 600°C, the modulus decreases around 20% and hardness drops more than 50% compared to the values determined at room temperature, which shows good comparability to literature data. Further, the nature of creep is investigated as a function of temperature. The dependency of the mechanical behavior related to the temperature secondary creep (steady state creep) is described by the relationship:

$$\varepsilon = A\sigma^{m}e^{-Q/RT}$$

where A is a constant factor, σ represents stress, m is a stress exponent, Q is an activation energy for the deformation process at the temperature, R represents gas constant, and T is the absolute temperature. The strain rate continuously changes during an indentation experiment with constant loading. During a single experiment, a connection between varying strain rates and applied stress is able to be determined. When the results of the strain rate are plotted against the hardness (mean pressure) (see Figure 3), the stress exponent, m, can be found. This exponent is used as an identifier for the underlying deformation mechanism taking place during the specified strain rate. While a high stress exponent, such as m=78.5 (for 300°C), is typical for an ODS material, a stress exponent of m=8.2 (600°C) is typical when thermally activated mechanisms, such as dislocation creep, are active.

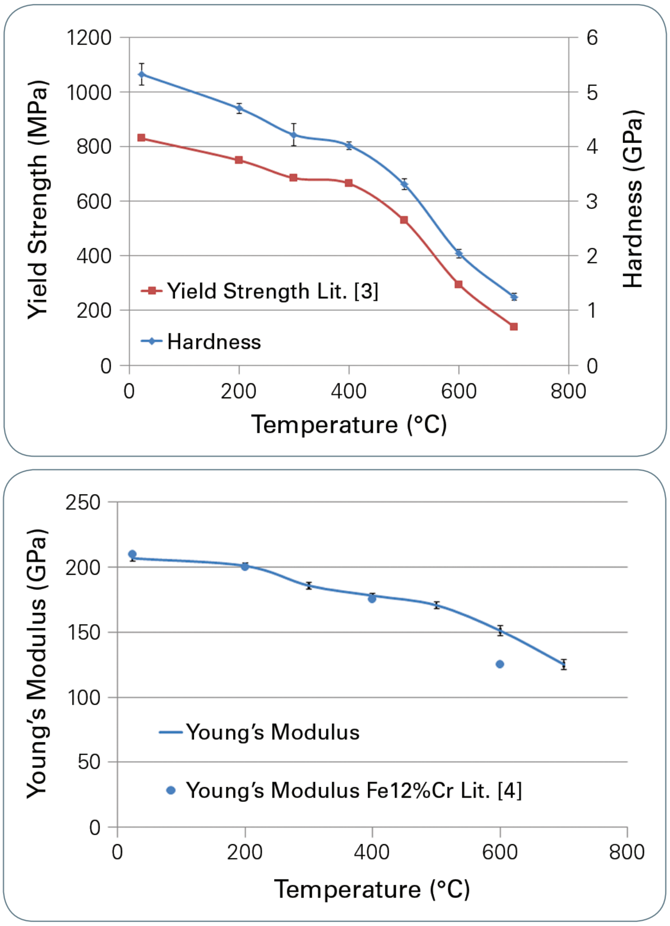

Figure 2. Hardness (top) and Young's Modulus (bottom) in a function of temperature and comparison to tensile test data.

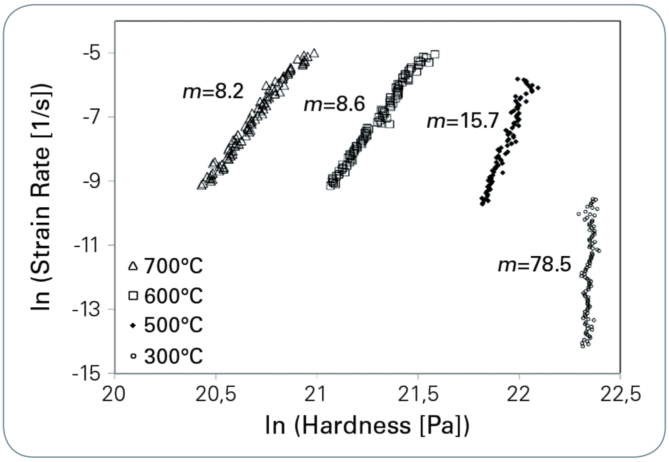

Figure 3. Strain rate in a function of hardness. The stress exponent, *m*, calculated for the different creep experiments is shown next to the relevant data.

Conclusions

The basic performance parameters of alloys can be studied by nanoindentation testing combined with the xSol High Temperature Stage. It was demonstrated that the nanoindentation approach was successfully used to identify two different deformation regimes in an ODS steel. It was also found that at temperatures below 500°C, the dispersion strengthening mechanism is active in the deformation. At higher temperatures, the onset of creep mechanisms is observed.

References

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