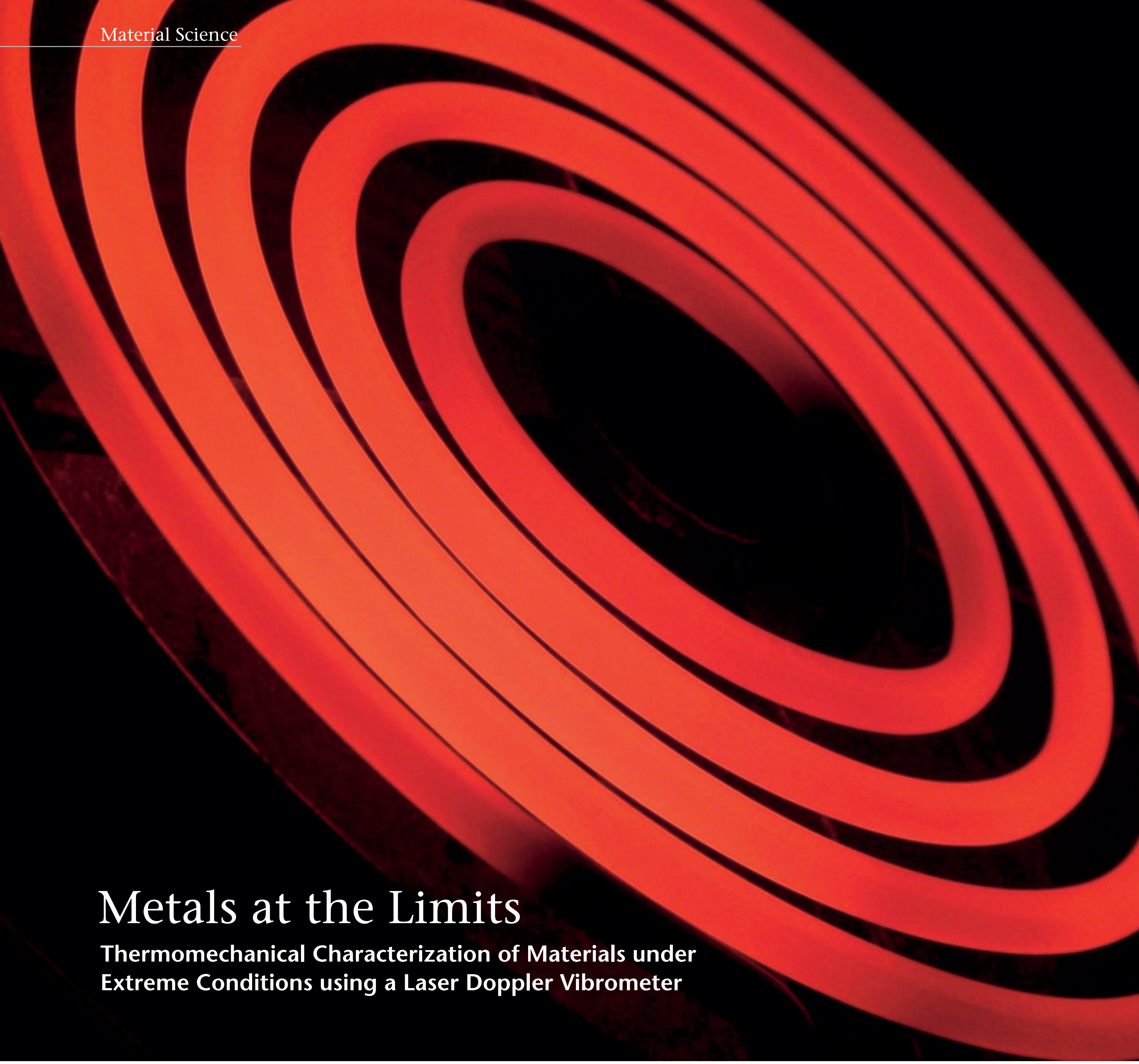

Metals at the Limits

Thermomechanical Characterization of Materials under Extreme Conditions using a Laser Doppler Vibrometer

A new dynamic method for thermomechanical characterization of candidate target materials (tungsten, tantalum and molybdenum) has been developed as part of the program advancing high power targets for the UK Neutrino Factory.

The materials used in the target systems of next generation high power particle accelerators are frequently exposed to a combination of high stresses, high strain rates and very high temperatures. To estimate the lifetime of target and target system components in this environment, the candidate materials have to be tested under extreme conditions.

Experimental Setup

A thin wire made from the candidate material was heated and stressed by a fast high current pulse (see fig. 1) generated by a power supply for the ISIS synchrotron (Rutherford Appleton Laboratory) kicker magnets. The wires were supported in a vacuum chamber to avoid oxidation and heated to 2650 °C by adjusting the pulse repetition rate. To allow the current to generate a sufficient thermal stress, the wire had to be thin (less than 1 mm diameter). A single-point Laser Doppler Vibrometer (LDV) comprising the OFV-534 optical sensor head and OFV-5000 vibrometer controller measured the longitudinal (by sensing at the

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wire tip) as well as radial velocities and displacements of the wires. Three different LDV decoder units (VD-02, VD-05 and DD-300) cover the complete range of amplitudes and frequencies of the wire vibrations. An optical pyrometer measured the wire temperature at the same point that was measured by the LDV.

Results and Conclusions

Fig. 3 shows the radial velocity of the tungsten wire measured by the Laser Doppler Vibrometer at different temperatures. The current pulse began at t = 0 and the wire started to contract and expand. After about 1 µs it reached a new equilibrium position and started oscillating around it. The time scale in fig. 3 begins with t < 0 in order to illustrate a relatively low background noise level of the LDV. The correlation between experiment and finite element modeling (LS-DYNA) calculations is very good. The radial oscillation frequency obtained was used afterwards to extract the Young's modulus of the wire material as a function of temperature. In fig. 4 the Young's modulus results from the new measurements are compared with earlier results.

To determine the yield strength, the current pulse amplitude in the wire was increased in steps. This was continued until the wire started bending or kinking. The radial surface velocity measured by the LDV (see fig. 3) was used to extract the strain rate during the test. The LDV optical sensor head includes a fast camera for monitoring strain in the wire. In addition, it was noticed that the LDV radial velocity signal became very noisy when signs of plastic deformation first appeared. This change in LDV signal quality indicated that the wire was near its yield point. Fig. 5 shows the stress that is needed to reach the yield point of molybdenum, tantalum and tungsten wires.

To conclude, the candidate materials for the Neutrino Factory target were tested under conditions expected at this accelerator. A new dynamic method for thermomechanical characterization of materials under extreme conditions was therefore developed that can help test the consistency of different constitutive models.

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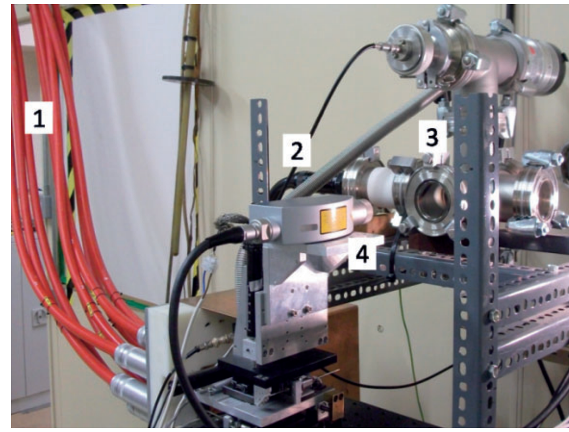

Fig. 1: The experimental setup. Coaxial cables (1) carrying the current pulse from the power supply are combined into a single cable (2) which is connected to the test wire. The wire is supported in a vacuum chamber (3) and its oscillations are measured by the Laser Doppler Vibrometer (4).

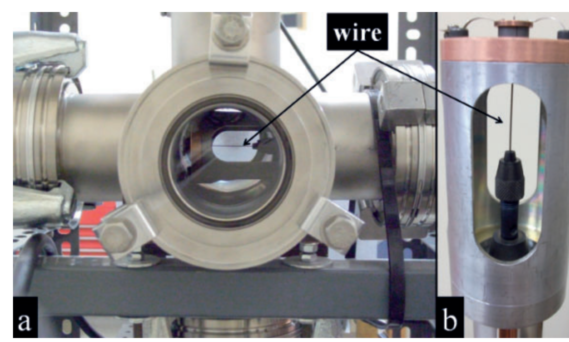

Fig. 2: Photograph of a 0.75 mm diameter tungsten wire during current pulse tests (a) and an illustration of wire clamping (b).

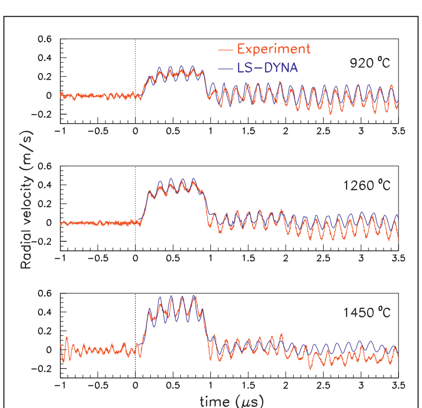

Fig. 3: The measured and calculated radial velocity of a 0.5 mm diameter tungsten wire at different temperatures.

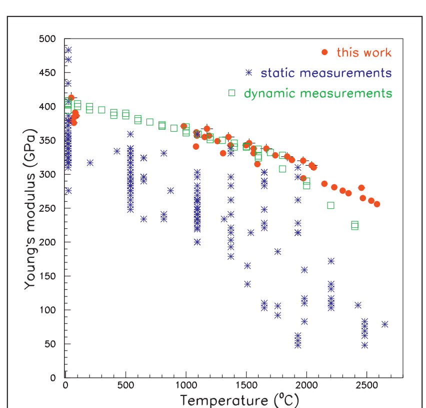

Fig. 4: Young's modulus of tungsten compared between experiments

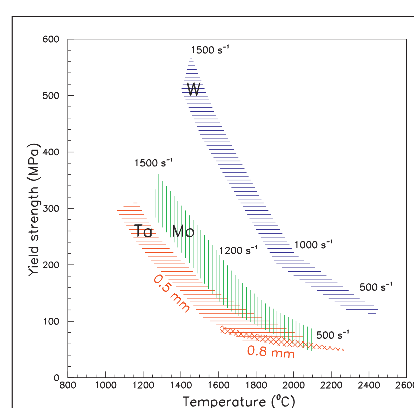

Fig. 5: The yield strength versus peak temperature for tantalum, tungsten and molybdenum wires. The characteristic strain rate values are also shown.

