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VIBRATIONS: SESSION A: STRUCTURAL ANALYSIS AND DAMPING

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The Measurement of Internal Damping at High Temperatures

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Fatigue problems in heat exchanger operation, particularly of gas-cooled reactors, indicate the selection of materials having maximum internal energy dissipation at the operating temperature, thus reducing the resonant excitation of heat exchanger tubes which might be induced, for example, by vortex shedding in gas flows. It was therefore required to measure the internal damping of heat exchanger tubes at high temperatures. Materials available were mild steel and various stainless steels suitable for investigation up to about 900°C and, considering future developments, silicon nitride for investigation up to about 1200°C. As the materials have relatively low internal damping, it was considered that measurement of the decay of resonant vibrations in free-free suspension was the preferred method. It may be shown that the Q - factor of the suspended system is given by

$$Q = \frac{f\pi}{0.115} \Bigg/ \left(\frac{dy}{dt}\right)_{dB}$$

where $Q = f/_{\Delta f}$, f is the resonant frequency, Δf is the 3 dB bandwidth at resonance and $\left(dy/_{dt}\right)_{dB}$ is the rate of decay of vibration level in decibels per second.

In the initial phase of the work, heat exchanger tubes approximately 1.8 metres long and several centimetres diameter were used. A furnace of internal dimensions 2m x 0.075m x 0.075m was constructed, heated by four Pyrobar elements each supplying 1240 Watts and which could be used up to a temperature of 800°C. The heat exchanger tube was suspended in the furnace at its nodal points by stainless steel wires. The tube was excited into resonance by a vibrator with an extended arm projecting through the wall of the furnace and contacting the tube via a small high-temperature spiral spring. The top of the furnace was closed with removable fire bricks through which the suspension wires passed. The temperature variation in the furnace at 750°C was ± 6°C.

The vibrator was withdrawn after the tube was excited to a suitable level of vibration and the decay monitored. Initial measurements at room temperatures were with standard wire strain gauges whilst it was intended to measure at the high temperatures with strain gauges which were rated for use up to 1100°C to a strain of 0.1%. The application of these small gauges, which were only six millimetres by three millimetres, required a complicated and intricate procedure taking eight hours, including the curing time of the high temperature cement. Unfortunately, after a small number of stress reversals, the gauges ceased to function and it was eventually concluded that the ceramic cement was fatiguing. Alternative cements produced similar failures and it was assumed that, although the high temperature gauges may be suitable for static stress work, they are not suitable for dynamic measurements. These difficulties led to the adoption of an alternative method for monitoring the vibrations of the tube, using a probe microphone to detect the acoustic signal radiated by the vibrating tube, assuming that this signal depends upon the amplitude of vibration at a given frequency. A stainless steel probe tube was used up to about 700°C and a quartz probe tube for the higher range of temperatures. The probe microphone was inserted through the wall of the furnace alongside the end of the sample with the tip of the probe a few centimetres from the surface of the sample. The decay of the resonant level was monitored on a logarithmic level recorder and the decay rate measured from the resulting trace. Pendulum motion of the suspended tube, either of a lateral or twisting type, results in amplitude fluctuations superimposed on the main trace, but these could be manually smoothed in determining the decay rate. Measurements of the variations of the resonant frequency of the given mode enables the change of Young's Modulus to be estimated.

Typical results obtained with 1.8m long tubes of mild steel and a chrome steel are shown in Figs. 1 and 2 for the fundamental modes of the tubes. Internal damping increases with temperature, whilst Young's Modulus decreases. However, other varieties of stainless and chrome steels produced less variation.

Later work was carried out on shorter specimens using a furnace operating up to 1200°C (with a variation of ± 2.5°) heated by silicon carbide elements. The quartz probe tube was used and the decay measured as before. The variation of Q and Young's Modulus with temperature for silicon nitride is shown in Fig. 3, whilst Fig. 4 gives similar measurements for Incoloy 800.

ACKNOWLEDGMENT

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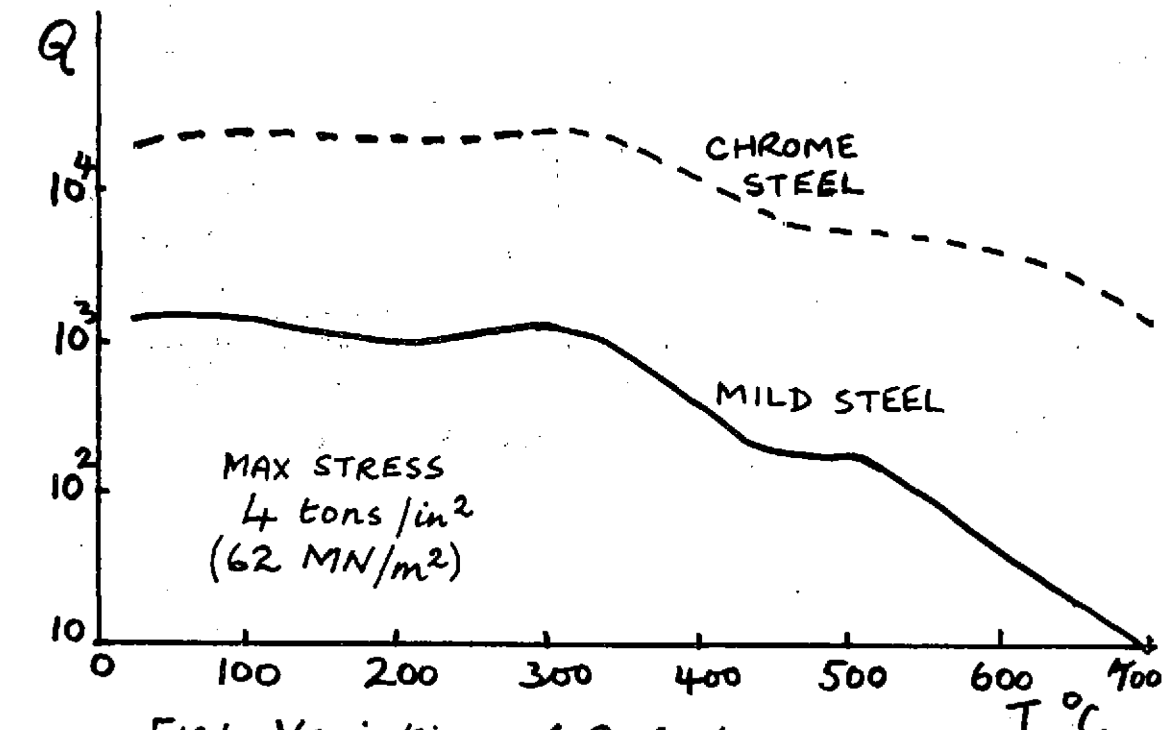

FIG 1. Variation of Q-factor

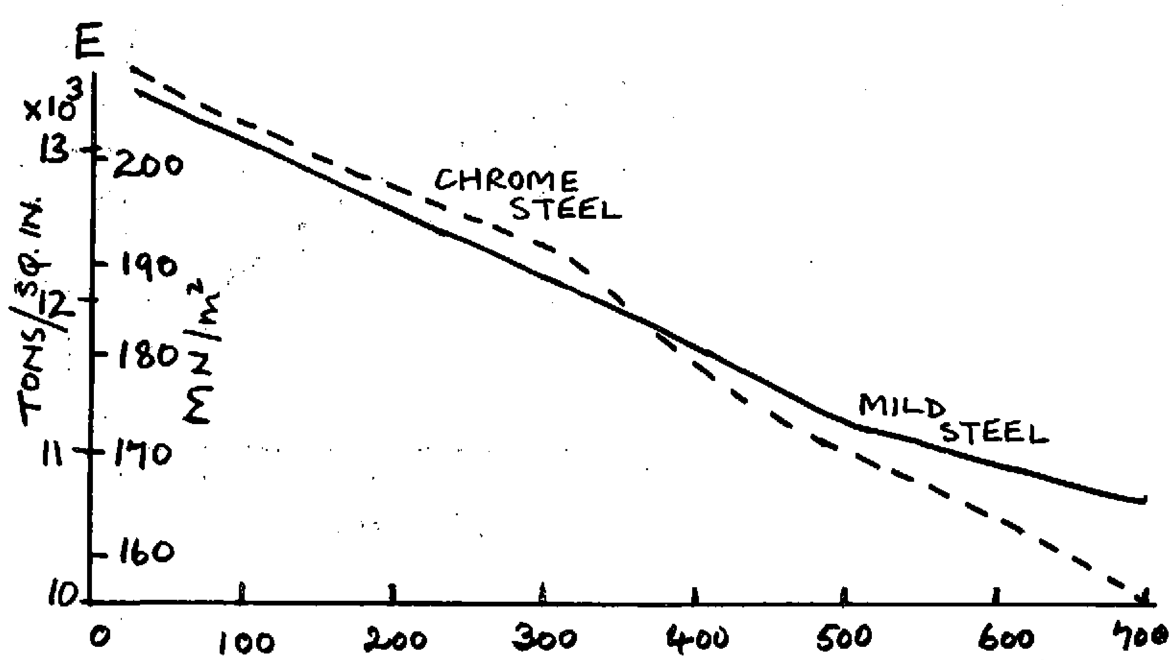

FIG 2. Variation of Young's Modulus.

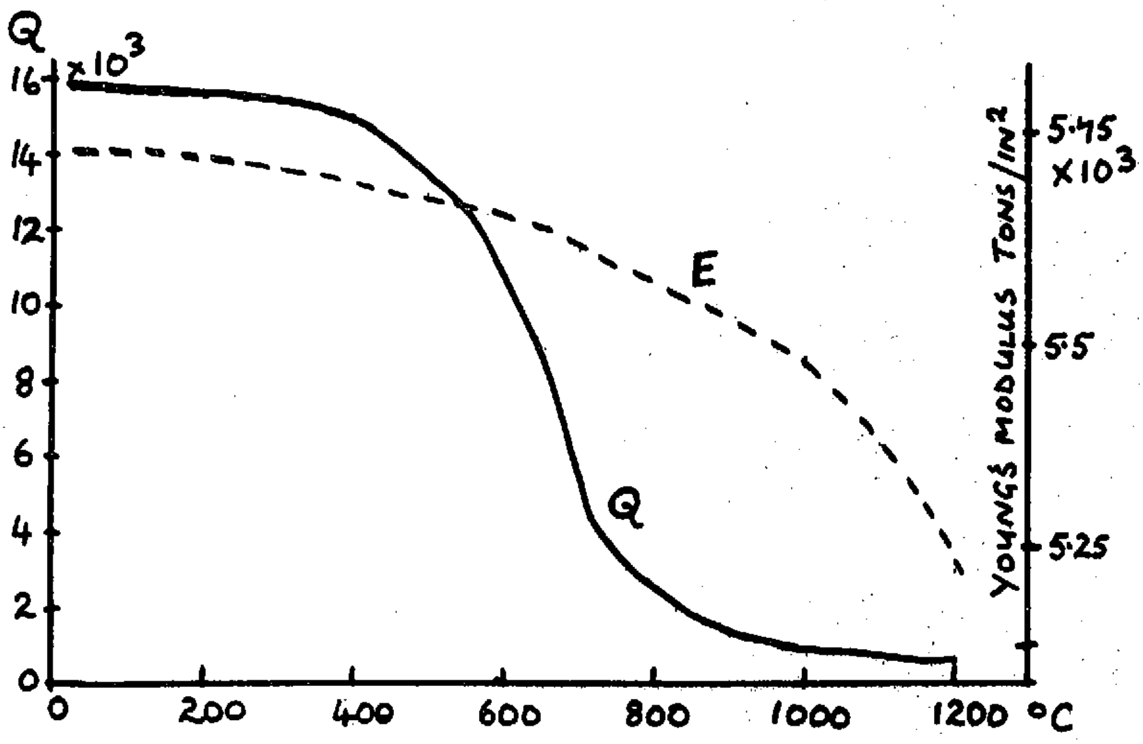

FIG 3. Damping and Young's Modulus of Silicon Nitride

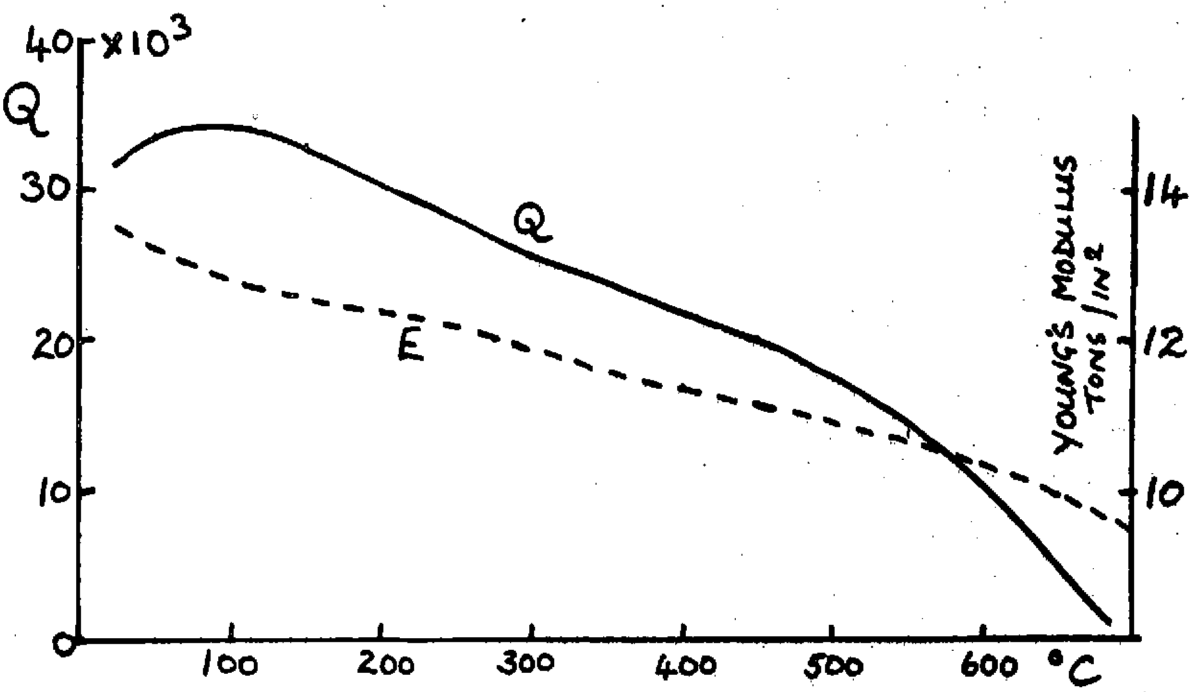

FIG 4. Damping and Young's Modulus of Incoloy 800