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The strength of thick-walled steel cylinders at elevated temperatures

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Abstract. A brief resumé of the reasons for requiring data on the hot strength of thick-walled cylinders and of the work so far published in the field is given.

The design of a torsion testing machine for use at elevated temperatures is described. Torsion data at temperatures from 20 to 370°C have been obtained for three steels: Hykro (EN40), Vibrac V30 (EN25) and a mild steel EN3. Tension data at the same temperatures have been obtained and are reported. Thick-walled cylinder pressure tests have also been carried out on these three steels at various temperatures up to 370°C and this information is presented.

It is concluded that the results have continued to demonstrate the simplicity and desirability of using shear stress-strain data, as derived from torsion tests on solid specimens, in the design of cylinders. However, with EN3 the agreement between experiment and theory in relation to the ultimate pressure is not nearly so good as with Hykro and Vibrac. This is due to the fact that EN3 cylinders fail on a rising pressure/expansion curve at strains below those needed to give the maximum pressure.

Introduction

The yield, flow, and fracture of thick-walled cylinders subjected to internal pressure has been extensively studied and a review of the literature is given by Crossland and Bones (1958). The current interest arises from the design of gun barrels, chemical reaction vessels, vessels for isostatic compaction, etc. In some of these cases the vessels operate at elevated temperatures. These temperatures are often sufficiently high to have a significant effect on the strength of vessels, though insufficient to give rise to the danger of short term failure by creep except at pressure close to the ultimate or maximum pressure which the vessel can contain.

Crossland and Bones (1958), Crossland, Jorgensen and Bones (1958), and Crossland (1964) have on the basis of papers by Manning (1945), Turner (1909), Cook (1934; 1938), and Morrison (1948) suggested a logical basis of design of thick-walled cylinders based on shear stress-strain data derived from torsion tests on solid or tubular cylindrical specimens. They have also published results of room temperature pressure tests on thick-walled cylinders, which show excellent agreement with theory based on torsion data. The only paper which reports results of tension and thick-walled cylinder tests at elevated temperatures is that of Faupel (1956). At initial yield the results showed reasonable agreement with values predicted from tension tests on the basis of the Maxwell or Mises-Hencky criterion. Reasonable agreement between the ultimate or maximum pressure found experimentally and those predicted by a completely empirically based equation was reported.

Unfortunately Faupel gave insufficient tension data to allow a more fundamentally based analysis suggested by Crossland, Jorgensen and Bones (1958) to be applied. No torsion data were reported, though shear stress-strain data have more direct relevance to the analysis of thick-walled cylinders subjected to internal pressure than tension data, as noted by Crossland (1964).

It was this paucity of information at elevated temperatures that led to the programme of work reported here, in which tension, torsion, and thick-walled

cylinder tests have been carried out on three steels at temperatures from 20 to 370°C.
Note that all data are given in tonf in^{-2} (= 2240 p.s.i. = 0·1544 kbar).

Apparatus and technique of testing

Figure 1 shows the torsion testing machine designed for carrying out torsion tests at elevated temperatures. The specimen is mounted in the oven in self-aligning grips to ensure that only a pure couple is applied. These grips are described in greater detail by Crossland (1965). One end of the specimen is coupled through a shaft to a torque bar external to the oven, and the other to a worm gear which can apply a twist to the specimen. The oven is fitted with a door with a double glass window for heat insulation through which the extensometer can be viewed. With full heating power the maximum temperature achievable is a little over 370°C.

Figure 2 shows the design of mirror clips used on the specimen. They consist of two stainless steel circular members with a degree scale scribed on their periphery,

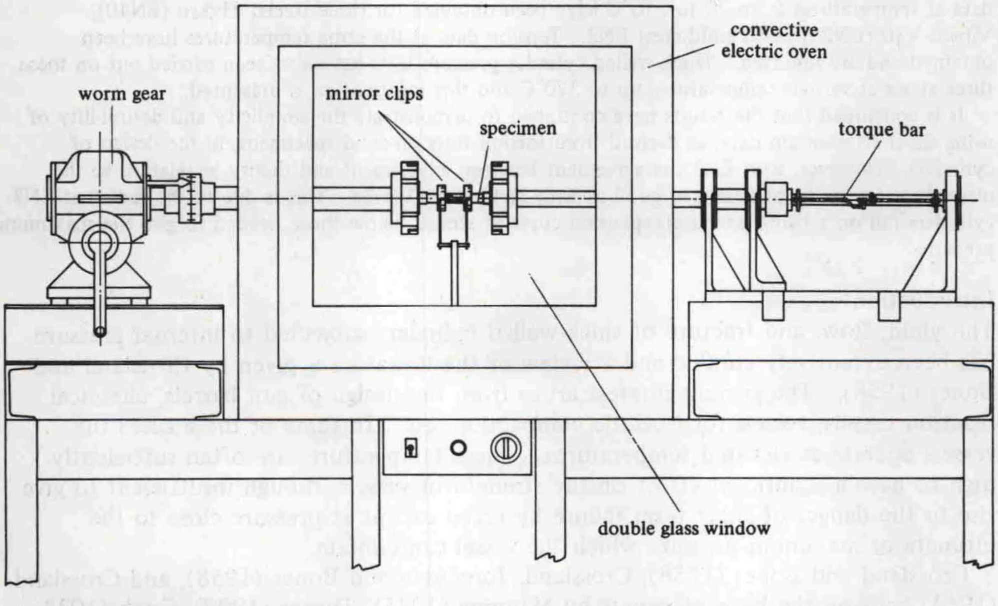

Figure 1. General arrangement of torsion testing machine for elevated temperatures.

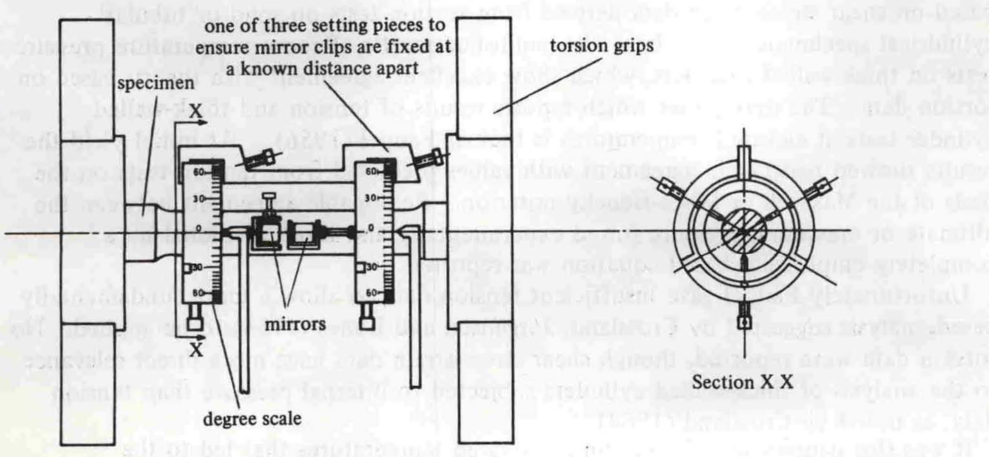

Figure 2. General arrangement of torsiometer for measuring small and large strains.