The Microstrains Observed in the Walls of Large Tubes under Internal Pressures up to 6 kbar

L. Deffet and J. Gouzou

INTRODUCTION

The study of the behaviour of thick-walled cylinders was initiated in 1960 by the Institut Belge des Hautes Pressions (IBHP). Previous tests had shown that a size effect existed at the onset of plastic strain and fracture of geometrically similar cylinders, i.e. of cylinders having the same outer diameter/inner diameter and length/diameter ratios, but different wall thicknesses (1)–(3)*. This size effect resides in the fact that small cylinders possess a better resistance to the progressive application of an internal pressure: they strain plastically and fracture at higher pressures than large cylinders. The relationships established by Lamé do not account for this difference: according to them, geometrically similar cylinders should strain plastically at a given pressure and burst at another pressure, both pressures being independent of the cylinder size.

This size effect was studied more thoroughly, from 1962, by IBHP and the Centre National de Recherches Métallurgiques (CNRM) working in close co-operation. The first results obtained showed that anelastic strains were observed in thick-walled cylinders earlier than generally thought, and led to a better knowledge of the stress distribution in these cylinders (4).

The present work was aimed at (1) checking whether or not thick-walled cylinders made from various steels exhibit a size effect at the onset of plastic strain, and (2) acquiring a better understanding of the phenomena which precede the onset of plastic strain in a thick-walled cylinder subjected to an internal pressure, in order to be in a position to calculate the complete stress distribution in such a cylinder.

STEELS USED IN THE TESTS

Four steels were used to manufacture the cylinders:

(A) a low-carbon steel;
(B) a medium-carbon steel;
(C) a quenched-and-tempered steel;
(D) an austenitic stainless steel.

The chemical composition and mechanical properties of these steels are listed in Table 1.

* *References are given in Appendix 2.*

TESTING

A comparison was made of the behaviour of geometrically similar cylinders with an outer diameter/inner diameter ratio of 2, and wall thicknesses ranging from 5 to 50 mm. These cylinders were subjected at room temperature to a progressively increasing internal pressure, and the following parameters were determined for each cylinder:

(1) the pressure corresponding to the onset of plastic strain;

(2) the strains present at the outer surface of the cylinder as the pressure is raised from zero to its maximum value.

The following rules were observed in order to obtain the best possible reproducibility:

(1) All the cylinders in a given series were manufactured from the same steel, in order to avoid any variation in the properties of material from one cylinder to the next.

(2) The length of each cylinder was approximately four times its outer diameter.

(3) Great care was taken to raise the pressure in all the cylinders of a series according to a strictly identical law, in order to ensure that the strain rate did not vary from one cylinder to the next.

(4) Pressures were measured by means of a free-piston gauge, with an accuracy of $0{\cdot}5\times10^{-3}$.

(5) The strains at the surface of the cylinders were measured by means of strain gauges with a sensitivity of 10^{-6}, the equipment used being capable of measuring the strains at 10 locations on each cylinder.

SIZE EFFECT

The test results confirm the existence of a size effect for steels A, B, and C: when geometrically similar cylinders made from the same steel are compared, it is seen that the pressure corresponding to the onset of plastic strain decreases slightly as the cylinder's size is increased.

In order to explain this size effect, the influence of microscopic material defects on the onset of plastic strain will be examined. As is known, the fracture strength of brittle materials has been tentatively attributed to the existence of defects or microcracks. Such microscopic

Table 1

Steel	Chemical composition, wt %							Mechanical properties, MN/m²	
	C	Mn	Si	Cr	Mo	Ni	Cu	Yield stress	Ultimate tensile strength
A	0·10	0·50	0·19	—	—	—	—	233	416
B	0·31	0·55	0·31	—	—	—	—	325	532
C	0·37	0·59	0·34	1·63	0·28	1·53	—	1076	1193
D	0·05	1·30	0·40	26·0	2·50	8·50	1·51	672	922