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THE BURSTING OF GLASS TUBES BY INNER HYDROSTATIC PRESSURE.

By Ryo Kiyama and Kazuo Inoue.

Introduction.

It is widely required to use the glass tube as a high pressure vessel, in order to observe or measure any high pressure reaction or the physical constants from the outside of the vessel.

A number of experiments have been made on the physical and mechanical properties of glass, but the experiments on the bursting strength of a glass tube for the inner pressure are only reported by Heydweiller[1], Schott and Herschkowitsch[2], and Onnes and Braak[2].

The safety of a glass tube is determined by the material of glass and the design of joint. The authors measured the bursting strength for the inner hydraulic pressure of a glass tube which is connected with the high pressure vessel by the joint of our design, and compared with the previous reports.

I. Annealed glass.

Experimental method.

a) The glass used and the removal of strain.

The glass tubes used are two kinds of commercial soda lime glass in Japan, A and B. The glass tubes are shown in Fig. 1, and the strain remains at a, b,

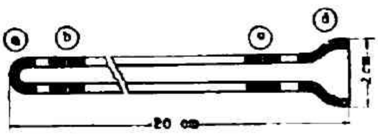

Fig. 1

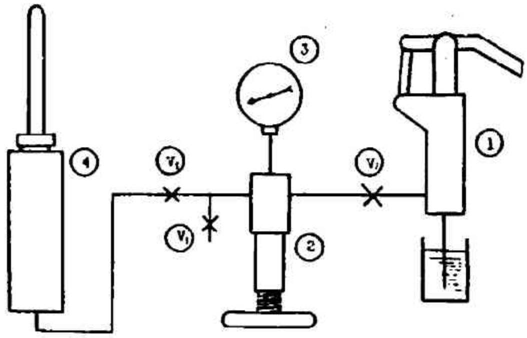

Fig. 2

1) G. W. Morey, *Properties of Glass*, 333 (1938)
2) *ibid.*, 334

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c, and d. The strain is removed by annealing, and investigated by polarized light.

b) Experimental apparatus and the operation.

Fig. 2 shows the hydraulic pressure apparatus which is used in this experiment.

(1) The plunger oil pump with a maximum pressure of 50 kg/cm^2.

(2) The oil pump driven by screw with a maximum pressure of 2000 kg/cm^2.

(3) High pressure gauge.

(4) High pressure proof chamber.

(V_1), (V_2), (V_3) High pressure valves.

Fig. 3 shows the structure of (4) in Fig. 2.

(5) Ni-Cr steel high pressure vessel: length 20 cm, external diameter 5 cm, internal diameter 2.5 cm, and capacity 50 cc.

(6) The cap of the vessel.

(7), (8) The rings of mild steel.

(9) The cap of mild steel.

(10), (11) Rubber packing.

(12) The ring of copper.

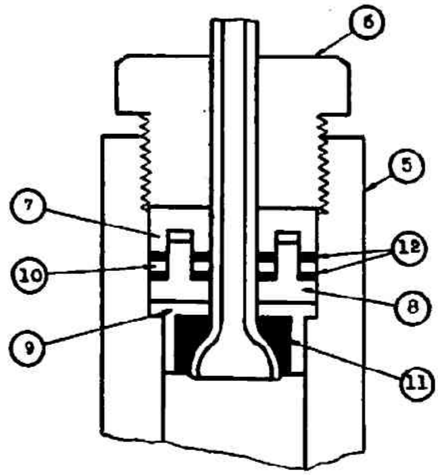

Fig.3

In measuring the bursting pressure, the glass tube is filled with oil and set into the chamber (4), then oil is compressed preliminarily by (1) and intensified continuously by (2). The speed of compression is 300 kg/cm^2 per minute.

Experimental results.

The results of experiment of glass A and B at room temperature are shown in Tables 1 and 2 respectively.

Table 1

Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.	Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.
1	7.6	4.9	1.6	240	7	7.5	1.8	4.2	430
2	7.4	5.0	1.5	225	8	7.5	2.0	3.8	380
3	7.8	3.9	2.0	200	9	7.2	3.0	2.4	350
4	7.7	4.0	1.9	240	10	6.7	2.3	3.0	320
5	7.9	2.2	3.6	430	11	7.3	2.3	3.2	320
6	7.6	3.1	2.5	370	12	8.5	6.0	1.4	180

13	8.5	6.0	1.4	220	19	8.0	1.3	6.2	350
14	8.5	6.0	1.4	240	20	7.7	1.0	7.7	280
15	8.5	6.0	1.4	260	21	8.4	5.7	1.5	230
16	8.5	5.7	1.5	230	22	7.7	1.2	6.4	450
17	8.3	5.6	1.5	270	23	7.7	1.2	6.4	380
18	8.1	5.6	1.5	270	24	8.2	1.3	6.3	480

Table 2

Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.	Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.
1	8.4	3.6	2.3	370	8	7.2	1.0	7.2	560
2	8.1	3.6	2.2	380	9	7.6	0.6	12.6	660
3	8.1	2.0	4.1	380	10	7.6	0.6	7.6	480
4	8.2	1.9	4.3	370	11	7.6	1.8	4.2	500
5	8.5	1.9	4.5	510	12	7.6	2.3	3.3	370
6	8.1	1.9	4.3	390	13	7.7	2.2	3.5	360
7	7.1	1.0	7.1	470					

Consideration.

The results of experiment are compared with the theories on the strength of cylinder which is subjected to the inner pressure.

In the Lamé formula, the maximum tensile strength T is equal to

$$T=\frac{n^2+1}{n^2-1}p, \tag{1}$$

in which p is the bursting pressure and n is the ratio of the external diameter to the internal one.

Assuming that the cylinder is broken by the maximum principal strain[3],

$$T=\frac{n^2(m+1)+(m-1)}{m(n^2-1)}p, \tag{2}$$

in which $1/m$ is Poisson's ratio.

Assuming that the cylinder is broken by the maximum shear stress, the following formula is given by Guest[4],

$$T=\frac{2n^2}{n^2-1}p. \tag{3}$$

By Onnes and Braak[1],

3) A. Morley, *Strength of Material*, 321 (1926)

4) *ibid.* 322

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$$T=\frac{1}{4}\left[5p+\left(7\frac{p-1}{n^2-1}\right)-1\right], \qquad (4)$$

in deriving this formula, Poisson's ratio is assumed to be 0.25.

The experimental results are compared with the above formulas in Figs. 4 and 5. Fig. 4 corresponds to the results of glass A (the maximum tensile strength

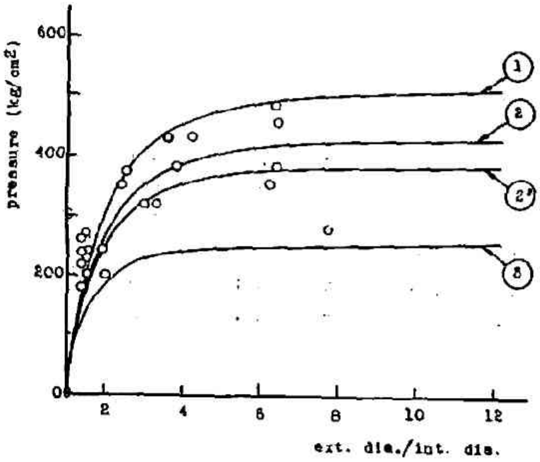

Fig. 4

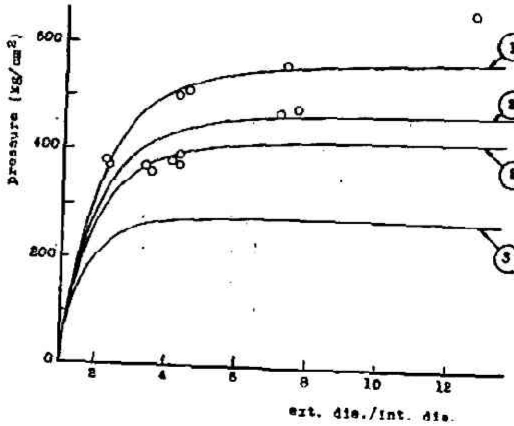

Fig. 5

520 kg/cm²) and Fig. 5 to B (580 kg/cm²). In these figures, Curve 1 corresponds to Eq. (1), and Curve 3 to Eq. (3). If Poisson's ratio is between 0.2~0.3, Eq. (2) is between Curves 2 and 2', and Eq. (4) falls between Curves 2 and 2'.

In these figures, the maximum bursting pressure seemed to follow the Lamé formula.

II. Strained glass.

The strength of the glass tubes which are cooled quickly (*i. e.* uniformly strained glass) is measured.

For the sample of glass, glass A is used, and maintained at 500~520°C for 2 hours, and cooled quickly to room temperature in air. The tubes by this treatment have, as a whole, the uniform strain.

The experimental apparatus and the operation are the same as in the case of annealed glass.

The results are given in Table 3, and show the intensification of pressure proof strength compared with annealed glass tubes.

In bursting, the strained tubes are scattered to fragments and are more brittle than annealed glass. From the size of fragments, it seems that the glass tubes of higher strength than Curve 1 in Fig. 4 are the incompletely annealed tubes in which the strain cannot be detected visually by polarized light.

Table 3

Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.	Exp. No.	Ext. dia.	Int. dia.	n	Bursting press.
1	8.5	6.0	1.4	170	5	8.5	6.0	1.4	290
2	8.5	6.0	1.4	250	6	8.5	6.0	1.4	300
3	8.5	6.0	1.4	270	7	8.5	6.0	1.4	330
4	8.5	5.9	1.4	290					

The strength of glass is influenced by various conditions as the time of annealing[5], the effect of moisture[6], the kind of gas contacted[6], the flaw of surface[7], the method of adding load[7], and the history of glass, etc. But as the results of the bursting experiment, it becomes possible for us to design the various experimental apparatus in which glass are used under high pressure.

Summary.

1. The method of the connection of glass with metal in a high pressure vessel is designed.

2. The maximum bursting pressure of annealed glass tubes for the inner pressure seemed to follow the Lamé formula in case of the ratio of the external diameter to the internal is smaller than 12.

3. When the ratio of the external diameter to the internal is larger than 2, the commercial soda lime glass in Japan may be used as the high pressure vessel in the pressure range, 200~300 kg/cm^2.

4. Strained glass tubes are stronger than annealed tubes, and are scattered to small fragments uniformly in bursting.

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5) J. L. Glathart and F. W. Preston, *J. App. Phys.*, 17, 189 (1946)
6) T. C. Baker and F. W. Preston, *ibid.*, 17, 179 (1946)
7) *ibid.*, 170