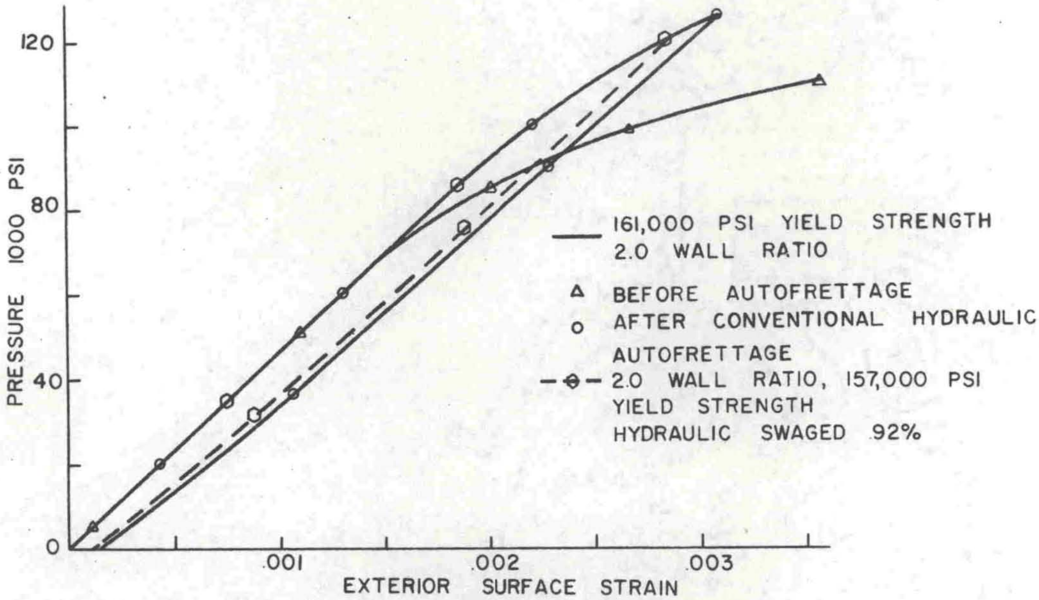

Fig. 9—Pressure-strain response for hydraulic-push-swaged specimen

or

$$\%\ \text{E.R.} = \frac{\epsilon_m (ID)_m + \epsilon_b (FD)_b}{(ID)_b} \times 100 \qquad (3)$$

where:

Δ = change in diameter
ϵ_b = tangential elastic strain at the bore
ϵ_m = tangential elastic strain at mandrel surface

For small deformations, eq (3) becomes

$$\%\ \text{E.R.} = (\epsilon_m + \epsilon_b) \times 100 \qquad (4)$$

From Lamé's equations,

$$\epsilon_b = \frac{P[(1-\mu) + (1+\mu)W^2]}{E\,(W^2 - 1)} \qquad (5)$$

and

$$\epsilon_m = \frac{P\,(1-\mu)}{E} \qquad (6)$$

Putting eqs (5) and (6) into (4) yields:

$$\%\ \text{E.R.} = \frac{P}{E}\left[\frac{200\,W^2}{W^2 - 1}\right] \qquad (7)$$

and finally by using

$$P = 1.08\,\sigma_{ys} \log W$$
$$E = 30 \times 10^6 \text{ psi}$$

eq (7) becomes:

$$\%\ \text{E.R.} = \frac{7.2\,W^2\,\sigma_{ys} \log W}{(W^2 - 1)} \times 10^{-6} \qquad (8)$$

Equation (8) is shown as solid lines and compared with experimental results in Fig. 7. The good agreement indicated permits eq (8) to be utilized for design purposes if the deformation of the cylinder is sufficient to produce yielding throughout the wall.

Mechanical-pull and Hydraulic-push Swaging

The utilization of the pull swaging and hydraulic-push swaging methods made it possible to study (1) the effectiveness of the lubricants under sustained high pressure and friction forces, (2) the ability of the mandrel to withstand these conditions over a longer period of time, (3) the general over-all effectiveness of the induced residual stresses in a long cylinder, and (4) the mechanical problems associated with these two methods. For these tests, four 40-in. specimens were swaged by pull swaging and two 40-in. specimens by hydraulic pushing. Each specimen was later cut into three equal lengths for the hydrostatic-yield comparison tests.

The pull-swaging-force records indicated force fluctuations varying in intensity according to the velocity of loading and the cylinder-wall ratio. These fluctuations were attributed to the elastic nature of the loading equipment and its inability to maintain a constant force. Reducing the wall ratio and increasing the velocity reduced the force required to overcome static friction and minimized the magnitude of the fluctuations.

In the specimen lengths tested, no apparent damage was done to the mandrel or the bore surfaces which, along with the small force magnitudes required, verified the practicality of the lubricants and the mandrel design.

The hydraulic-push method utilized hydraulic pressure applied directly to the back face of the mandrel in order to push it as shown in Fig. 2. The mandrel contact with the cylinder walls provided a very good forward movable seal with the initial seal being obtained from pressing the mandrel into position. The required pressure for this method was obtained from a 200,000 psi high-pressure system used for conventional autofrettage. Considerable fluctuations in pressure revealed the inadequacy of the system to compress the liquid in sufficient volume to maintain a constant force against the mandrel. This condition, together with the higher force requirement needed to overcome static friction as compared with moving friction, resulted in nonuniform motion