u = radial displacement
PER = permanent enlargement ratio

Subscripts
t = tangential
r = radial
z = longitudinal
p = plastic region
e = elastic region
0 = 100 percent overstrain condition

INTRODUCTION

The requirements for pressure vessels of high elastic load carrying capacity is rapidly increasing as evidenced by the rapid advancements in such fields as chemical processing and hydrostatic compacting. Similarly, in such fields as cannon, there is a constant aim towards increasing the strength to weight ratio of weapons. Along with this trend towards higher pressures in these and other fields, the design and fabrication of pressure vessels becomes increasingly difficult. A point is reached where it is no longer feasible to simply increase the diameter ratio and/or the basic material strengths and it becomes necessary to consider other means of increasing the elastic load carrying capacity. The most common techniques for increasing the elastic load carrying capacity are jacketing, wire wrapping and autofrettage. All of these techniques are based on the use of induced residual stresses to counteract the operating stresses. Autofrettage, however, is the most efficient. It has been the purpose of the work summarized in this paper to study the application of the autofrettage principle to pressure vessels fabricated from current high strength materials.

Autofrettage is a process in which a favorable residual stress distribution is produced by subjecting the cylinder to an internal pressure of sufficient magnitude to cause plastic flow in part or all of the cylinder wall. When the pressure is released, residual stresses are set up which are compressive near the bore changing to tensile towards the outside surface. These residual stresses oppose the operating stresses, thus increasing the elastic load carrying capacity of the vessel.

Several investigators have studied the theoretical solution in terms of the stresses and strains associated with the overstrain of thick-wall cylinders. These solutions, however, are primarily based on the Tresca yield criterion and, although simple by comparison, they are inherently inaccurate as compared to those based on the von Mises yield criterion. Unfortunately, however, the use of the von Mises criterion results in very complex relationships that often cannot be obtained in closed form.

The experimental study of the overstrain of thick-wall cylinders in the past has been primarily limited to low-strength materials by today's standards. Consequently, much of the data is inaccurate and incomplete when applied to current high strength materials.

This paper summarizes a portion of the results of an experimental program associated with the study of the overstrain of thick-wall cylinders in the diameter ratio range of 1.4-[illegible] and nominal yield strength level of 165,000 psi. Experimental data are presented for the pressure required for, and the displacements associated with the 100 percent overstrain condition. Using empirical relationships, the solution for the open-end cylinder condition using the von Mises criterion is presented. Simplified relationships are given and compared to the experimental data for both the stresses and displacements in the plastic and elastic portion.

In addition to those subjects covered within this paper, other phases of the study of overstrained thick-wall cylinders are under way and will be reported at a later date. Included are experimental determinations of the residual stress distribution, effects of material removal and temperature on the elastic strength, and progressive stress damage studies.

DESCRIPTION OF TESTS AND APPARATUS

Test Specimens

The specimen geometry consisted of a common initial 1-in. bore diameter with a length of 11 in. This length was determined to be great enough to overcome end effects in the largest diameter ratio investigated.

All specimens were obtained from 4340 steel billets 80 in. long and [illegible] in. in diameter which were gun drilled and cut into two 40 in. lengths. These lengths were heat treated by austenitizing at 1525°F, oil quenching in the longitudinal direction and tempering at 1075°F ± 25° with a resultant nominal yield strength of 165,000 psi. Each heat treated bar was then finish reamed to 1 in. I.D. and cut to obtain three 11 in. specimens. The remaining 7 in. of material provided tensile and charpy specimens.

Restraining Containers

Preliminary experimentation was conducted using several specimens, ranging in diameter ratio from 1.4 to 2.4, to determine the uniformity of strain along the specimen length. Due to the natural inhomogeneity of material, particularly at this high strength level, large variations in plastic dilation were noted, both along the length and circumferentially. Therefore, to insure uniform deformation throughout, external restraining containers were utilized. These containers were split at the half-length point and recessed to allow the application of strain gages to the specimen surface as shown in Fig. 1.