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OVERSTRAIN OF HIGH-STRENGTH OPEN-END CYLINDERS OF INTERMEDIATE DIAMETER RATIO

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Abstract—Those associated with the pressure vessel field have long been interested in means for increasing the elastic load carrying capacity of thick-wall cylinders. Over the years, such techniques as wire wrapping, bore quenching and the more common jacketing and autofrettage have been utilized.

Recent requirements in the pressure vessel and weapons fields now make it necessary to consider means for even further increasing the elastic load carrying capacity of cylinders fabricated from high-strength materials. This paper describes the results of an experimental program associated with the application of the autofrettage principle to materials in the 160,000–190,000 psi yield strength level and diameter ratio range of 1.4–2.4.

Data are presented for the elastic breakdown and full overstrain pressure as a function of diameter ratio and compared to that theoretically predicted based on the Tresca and von Mises yield criteria.

Data are also presented for the permanent enlargement and enlargement ratio associated with the complete overstrain condition.

Also presented is a system of simplified equations for the stresses and strains in both the elastic and plastic regions of an overstrained open-end cylinder. These equations are based on an approximation of the von Mises yield criterion and show very good agreement with the experimental results.

LIST OF SYMBOLS

P = pressure
ϵ = unit strain
σ = stress
σ_y = yield stress
r = variable radius
a = inside radius
b = outside radius
ρ = radius of elastic—plastic interface
W = diameter ratio, b/a
μ = Poisson's ratio
E = Young's modulus of elasticity
PF = pressure factor, P/σ_y
SF = strain factor, $\epsilon E/\sigma_y$

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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