New Approach to the Autofrettage of High-strength Cylinders

An oversize mandrel is forced through a 4340 steel tube to plastically deform the walls and, thereby, produce favorable residual stress patterns

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ABSTRACT—The usual method of autofrettage (cold working) for gun tubes utilizes hydraulic pressure applied directly to the bore in order to plastically deform the wall of the tube so that favorable residual-stress patterns are produced. The strength of the tube is effectively increased, providing many associated benefits; however, ultra-high hydraulic pressures are required for high-strength steels since plastic-flow pressure is directly proportional to the yield strength of the material.

A new method for the autofrettage of high-strength steel cylinders requiring greatly reduced pressures is developed and described herein. An oversize mandrel is forced through the tube to plastically deform the walls. Three methods of forcing the mandrel are investigated. Mechanical-push swaging is used in the autofrettage of short 5-in. long specimens with pull swaging and hydraulic-push swaging being used on specimens 40 in. long.

All specimens are made from 4340 steel heat treated to various strengths. Cylinders with wall ratios ranging from 1.5 to 2.8, yield strengths ranging from 90,000 to 180,000 psi, and percent enlargements at the bore ranging from 1.0 to 5.0 are utilized.

An engineering analysis is made investigating such factors as percent enlargement and elastic recovery at the bore, the ratio of pressure required for pushing the mandrel to the yield strength of the material, the effects of various lubricants on the frictional forces involved, and the induced three-dimensional stresses in the cylinder walls.

Sach's boring-out technique is used to evaluate induced residual-stress patterns. Strains are recorded with electric-resistance strain gages and the associated dynamic and static instrumentation is described. Results are presented in graph form.

List of Symbols

$E.R.$ = elastic recovery
FD_b = final diameter of the bore after compression
ID_b = initial diameter of the bore before compression
ID_m = initial diameter of the mandrel before compression
FD_m = final diameter of the mandrel during compression
P = internal hydrostatic pressure, psi
W = wall ratio (ratio of outside to inside diameters)
E = Young's modulus of elasticity
Δ = change in diameter
σ_{ys} = yield strength, psi
τ = shear stress
ϵ_y = strain at yield on the outer surface
ϵ_b = tangential elastic strain at the bore
ϵ_m = tangential elastic strain at mandrel surface
μ = Poisson's ratio

Introduction

The Autofrettage Process

Autofrettage is a process for inducing elasticity in a gun tube at pressures which otherwise cause plastic strains. The conventional process is one of subjecting a monobloc tube to internal pressure of sufficient magnitude to permanently enlarge the bore a predetermined amount. As the internal pressure is released, the outer portion of the tube attempts to resume its original dimension, however, the material near the bore resists this movement. Consequently, tangential compressive stresses are induced in the material near the bore and tangential tensile stresses remain in the outer material.

The strength of the tube is thus effectively increased and may be utilized as follows, (1) a non-autofrettaged monobloc tube may safely have the wall ratio W reduced for a given maximum internal pressure, or (2) without changing the wall ratio the internal pressure may be safely increased.

The autofrettage principle can be applied to steel cylinders of very high yield strengths. For these materials, the small increase in strength caused by strain hardening associated with plastic deformation is negligible compared to the increased strength resulting from the residual stresses induced by the autofrettage process.

The conventional hydraulic method utilizes a press to restrain pressure-retaining packings, and also external restraining containers whose internal diameter is used to control the amount of radial plastic deformation. In view of many problems encountered utilizing the conventional hydraulic method of autofrettage of high-strength cylinders, an alternate method has been developed. Experiments on this new method, known as the swaging method, are presented and described.

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