Autofrettage by Swaging

The swaging method of autofrettage basically consists of passing an oversize swaging tool (mandrel) through the bore of the cylinder. The mechanical advantage gained from the sliding cone is used to expand the cylinders until yield conditions are obtained throughout the walls.

Three different methods of forcing the mandrel were studied, (1) the mandrel was mechanically pushed by means of a ram and hydraulic press, (2) an overhead crane pulled the mandrel and (3) the mandrel was pushed by applying hydraulic pressure directly to the end of the mandrel.

The majority of this paper is concerned with experiments utilizing the mechanical-push method on specimens approximately 5 in. long. Longer specimens were tested in order, (1) to examine the feasibility of swaging by mechanically pulling the mandrel and by pushing the mandrel using direct fluid contact, (2) to determine the effects of longer contact distances and (3) to provide specimens of sufficient length for hydrostatic yield tests.

Four basic wall ratios: 1.5, 1.9, 2.3 and 2.8, and four nominal yield strengths: 90,000, 130,000, 150,000 and 180,000 psi were tested and evaluated. Nominal predicted increments of bore enlargement were: 1.0, 2.5, 3.7 and 5.0%

Copper plate and molybdenum disulfide were used as lubricants to prevent seizure and scoring between the mandrel and bore surfaces which were in contact under very high pressure and friction conditions. Instrumentation included the use of dial bore gages, rms surface-finish indicators, SR-4 electric-resistance gages, Baldwin strain indicators and Brush and Edin dynamic strain recorders. Radial, tangential and longitudinal stresses were evaluated using Sach's boring-out technique. Percent enlargement and elastic recovery at the bore, surface finish changes, and the ratio of pressure required to push the mandrel to the yield strength of the material were also evaluated.

Description of Tests and Test Apparatus

Swage Specimens

All specimens were prepared from the same heat of Type 4340 steel forgings $4^1/_4$ in. in diameter and 80 in. long. The chemical analysis showed the following content:

Carbon	0.37	Nickel	2.39
Manganese	0.72	Chromium	0.98
Silicon	0.28	Molybdenum	0.38
Sulfur	0.035	Phosphorous	0.016

Specimen lengths cut from the forgings were drilled to $1^1/_4$ in. internal diameter before heat treatment. One specimen from each heat-treated lot was used to determine the mechanical properties of the material.

The before-swaging bore dimensions of the 5-in. mechanical-push specimens were obtained by machining and grinding. Outside and inside diameters were varied to obtain the desired permanent bore enlargements for the various wall ratios. Tests on the short specimens included all four basic yield strengths of 90,000, 130,000, 150,000 and 180,000 psi.

The 40-in. pull-swaging specimens were heat treated to 127,000 psi yield strength and machined to obtain a nominal 2.5% bore enlargement. The wall ratios were kept the same as the 5-in. specimens. The 40-in. direct-hydraulic-push specimens were heat treated to a nominal 160,000 psi yield strength, machined to a 2.0 wall ratio, and threaded at one end to receive a special high-pressure seal fitting.

Swage Mandrels

Several mandrel designs varying from spherical to cylindrical were considered. Such factors as friction, localized enlargement of the specimen bore, lubrication and tool alignment were considered in arriving at the final configuration. Figure 1 illustrates a typical design.

Several combinations of materials and surface treatments, along with minor changes in the length of flat surface and in the rear taper, were investigated. An angle of approach of 1.5 deg was maintained for all mandrels and a ground and polished mandrel surface finish of 2–15 microinches was provided to reduce friction. Other nominal dimensions consisted of $1^1/_2$ in. major diameter, $^3/_4$ in. flat width, and a rear taper of 3 deg to facilitate elastic recovery.

Mechanical-pull Swaging

The mandrel used in pull swaging was made in the form of a cylinder and attached to a long pull rod by shrinking. Figure 2A shows an assembly of the pull rod, attached mandrel and 40-in. long specimen. An overhead crane provided the power source.

The holding fixture for the specimen was composed of a steel cylinder of 10 in. outside diameter and 1-in. wall thickness. The ends were capped and possessed holes just large enough for the mandrel and pull rod to pass through. External cones at the ends centered the specimen and buckling was prevented by set screws at two points along the length of the specimen. This fixture was mounted on the bottom of the yoke of a 10-million pound press with the pull bar extending upward through a hole in the yoke.

To measure the force in the pull bar, SR-4 Type A-1 strain gages were attached to the pull rod diametrically opposed at the quarter points to form one arm of a Wheatstone bridge. In this manner, induced bending strains were eliminated and only axial strains were recorded. Calibration of this circuit directly into tons was accomplished using a tensile-testing machine. Continuous recording was made possible with a Baldwin dial strain recorder.

Hydraulic-push Swaging

Several longer specimens were swaged with hydraulic (glycerine and water) pressure applied directly