SECTION 3

ANALYSIS OF SEVERAL HIGH-PRESSURE CONTAINER DESIGN CONCEPTS

XXIII

SUMMARY FOR SECTION 3

Five types of pressure-vessel designs were analyzed in detail: a multiring container, a ring-segment container, a ring-fluid-segment container, a pin-segment container and a ring-fluid-ring container. (These are illustrated in Figures 39 and 40 of the text.) The multiring container is made up of cylindrical ring components. The ring-segment container is like the multiring container except that the second ring, adjacent to the liner, is a segmented ring. The ring-fluid-segment container is a combination of a ring-segment container on the inside with a multiring container on the outside, and with a fluid support pressure in between. In the ring-fluid-ring container, the inner ring is of single or multiring construction. The pin-segment container has a cylindrical inner liner supported by a pinned segment-plate arrangement. A wire-wrapped (strip-wound) vessel and a controlled fluid-fill vessel were also considered but in less detail.

The four types of pressure vessel designs shown in Figure 39 were analyzed and reported in Interim Reports III, IV and V.[20, 21, 22] These analyses are described in detail in this section. Though the concept of the ring-fluid-ring design was reported in Interim Report IV, its complete analysis is reported for the first time in this section.

The operating cycle of high-pressure containers for hydrostatic extrusion and forming consists of application of the pressure needed, followed by a decrease in the pressure to zero. Such highly cyclic conditions coupled with extreme operating pressures can be expected to cause fatigue failures of the containers. A fatigue strength criterion was selected as the basis of the study because a high-pressure container for commercial application should, of course, be capable of repeated use without frequent failure.

To achieve the desired high pressure it was found necessary to use high-strength liner materials. For the high-strength steels (ultimate tensile strengths of 250,000 psi and greater) a maximum-tensile-stress criterion of fatigue was assumed and available uniaxial fatigue data from the literature were used in design evaluations. However, the fatigue behavior was left arbitrary in the analysis by formulating the analysis in terms of α_r and α_m, semirange and mean tensile stress parameters. The outer rings of the containers were assumed to be of more ductile materials in order to avoid catastrophic failures. A maximum shear criterion of fatigue was used for the ductile outer rings and the Goodman relation was used to relate the semirange and mean shear stresses.

For the analysis, equations were derived that relate the interface and the radial deformations between components. Elasticity solutions for stress and deformations were used together with fatigue relations to determine formulas for maximum bore pressures. Stresses due to the bore pressure and shrink-fit assembly were analyzed. The effect of temperature change (from operating temperature to room temperature) upon the prestresses (residual stresses) was included. The analyses for maximum pressure capability, residual stresses, and required shrink-fit interferences were programmed for calculation on Battelle's CDC 3400 and CDC 6400 computers.

Theoretically, large pressures (up to 1,000,000 psi in the ring-fluid-segment design) were found to be possible in the containers. However, designs based on the theoretical pressures were not always considered practicable because of manufacturing and assembly limitations. For example, a ring-fluid-segment container designed to a theoretical maximum pressure capability of 450,000 psi requires outside diameters of 88.0 inches and 218.0 inches for 6- and 15-inch-diameter bore designs, respectively. Such large-diameter cylinders would present problems in producibility, heat-treating, and transportation. This container design also requires a shrink-fit interference of 0.0128 in./in., which is difficult, if not impossible, to achieve in assembly. This large interference requirement is necessary to overcome excessive deformation of segments. Also, relatively larger outside diameters are required for segmented containers because segments offer no hoop support to the liner. These are distinct disadvantages of containers using segments.

Because of the practicable design limitations, the designs were evaluated for outside diameters limited to 72 inches and interferences limited to 0.007 in./in. maximum. High-strength liner materials of 300,000 psi ultimate tensile strength were assumed for which some fatigue data were available. A fatigue life of 10^4-10^5 cycles was selected for ideal conditions, i.e., no stress concentrations or material flaws in the liner. On this basis, the predictions of maximum pressure capability for 6-inch-diameter bore designs, for example, are as follows:

Container	Outside Diameter, inches	Maximum Pressure, p, psi
Multiring	51.0	300,000
Ring-segment	60.0	290,000
Ring-fluid-segment	72.0	286,000
Pin-segment	72.0	195,000

These pressure capabilities apply at room or elevated temperatures, provided the ultimate strength of the liner is 300,000 psi at temperature. Higher maximum pressures are theoretically possible with higher strength materials. For example, a maximum pressure of 450,000 psi would be predicted for a multiring container with a 450,000 psi ultimate strength liner material, if such a material could be found that had the same proportionate increase in its fatigue strength.

Residual stress limitations were also found for containers designed for high-temperature use. If the coefficient of thermal expansion of the liner is smaller than that of the outer components, then a decrease in temperature from operating temperature to room temperature may cause excessive residual stresses in the liner. Therefore, a higher coefficient of thermal expansion would be recommended for the liner.

There are other possible material limitations. The design evaluations conducted herein were based necessarily on the uniaxial fatigue data available for the liner materials, although a biaxial or triaxial state of stress exists in a pressure container. Also, a compressive mean stress on the liner was assumed beneficial. However, fatigue behavior of high-strength steels under combined stresses and compressive mean stress is unknown. In addition to fabrication and transportation difficulties, heat treatment of large cylindrical forgings may also present problems. In this respect a pin-segment-plate arrangement or a strip-wound layer offers advantages as a replacement of cylindrical rings for outer support members.