DEVELOPMENT OF THE MANUFACTURING CAPABILITIES OF THE HYDROSTATIC EXTRUSION PROCESS

SUMMARY

HYDROSTATIC EXTRUSION STUDIES

Hydrostatic extrusion trials were continued to evaluate the critical process variables and specific process application studies were begun. The billet materials extruded were AISI 4340 steel, 7075-0 aluminum, and Ti-6Al-4V titanium alloy.

In extrusion of AISI 4340 rounds, the extrusion pressures were decreased 8 per cent by raising the stem speed from 1 to 6 ipm and then remained essentially constant up to 80 ipm, the maximum speed of the press. At 80 ipm, the "effective stem speed" was actually 148 ipm, which is well within the range used in commercial extrusion operations. In a study of hydrostatic fluid media, water was found to be very effective up to 185,000 psi, the maximum pressure reached thus far. Use of water in a commercial production operation would offer the advantages of low cost and ease of handling. In a study of die angles from 30 to 90 degrees, 45 degrees was found to be nearly optimum from the standpoint of minimizing pressure requirements.

The 7075-0 aluminum alloy was extruded into rounds at ratios up to 60:1 at room temperature. At a ratio of 20:1, the alloy was extruded at exit speeds up to 3000 ipm without surface cracking, a condition that is usually encountered in conventional hot extrusion unless the exit speeds are kept down to around 10 to 50 ipm. The problem of billet lubrication of 7075 Al during hydrostatic extrusion is alleviated by operating at stem speeds of 80 ipm. In a study of billet surface finish, grit-blasted finishes were effective in minimizing extruded-surface cracking and improving surface finish but were not able to prevent stick-slip.

In extrusion of Ti-6Al-4V rounds, several new billet lubrication systems were evaluated. Some appear promising and modifications of them are underway to obtain additional improvements.

A new die design for extrusion of a T-section was evaluated. The die entry consisted of a 45-degree conical surface leading into a 160-degree conical surface, the latter circumscribing the T-opening. T-sections of excellent surface quality were extruded from 7075 Al at a ratio of 7.3:1 and stem speeds up to 80 ipm from the die.

One of the strong potential applications of the hydrostatic extrusion process is for the production of tubing. A tooling arrangement for tube extrusion was designed and evaluated. Sound tubing, 0.750 inch ID x 0.063 inch wall, was produced from 7075 Al at a ratio of 12.2:1 and exit speeds of 450 ipm, the maximum ratio and speed attempted thus far. AISI 4340 tubing of high surface quality was produced at a ratio of 3.77:1. A problem of frictional drag between the tubing and mandrel was encountered, but it appears that this can be overcome by a slight modification of the mandrel.

ANALYSIS OF SEVERAL HIGH-PRESSURE CONTAINER DESIGN CONCEPTS

Four types of pressure vessel designs were analyzed in detail: a multi-ring container, a ring-segment container, a ring-fluid-segment container, and a pin-segment container (These are illustrated in Figure 7 of the text.). The multi-ring container is made up of cylindrical ring components. The ring-segment container is like the multi-ring 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 multi-ring container on the outside, and with a fluid support pressure in between. 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 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 high pressure desired 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 computer.

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 its theoretical maximum pressure capability requires outside diameters of 229.5 inches and 573.5 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 0.016 in./in., which is difficult, if not impossible, to achieve in assembly. This large interference