the case on metallographic examination of other specimens taken close to the origin of failure. In spite of the relatively large size of the suspected defect, however, it is still far below the sensitivity range (3/64 inch) of the ultrasonic equipment used to inspect the liner during fabrication. Detection would have been made even more difficult, of course, if the protrusion had filled the void completely at the time of testing.

Electron microscopic fractography was employed to determine the mode of crack propagation in the vicinity of the origin. A standard two-stage plastic carbon replication technique was used to obtain replicas of an area approximately 0.1 inch^2 containing the above described void. Examination at a magnification of 12,200X revealed the fractured surface to be generally flat and featureless with localized regions containing very fine fatigue striations. The fatigue striations are indicated by the arrows in the electron microscopic fractograph shown in Figure 71. The small spacing of the striations suggests that crack growth may not have been due to the extrusion pressure cycles alone, but also to a vibration or pulsation superimposed on the high pressure. An obvious source of this vibration is the hydraulic pump of the press which can transmit pulsations to the liner by way of the stem and hydrostatic fluid. The extent to which such vibrations may have contributed to the rate of crack growth is not known.

Another feature of significance is evident in the fractograph shown in Figure 72. This is the typical cleavage-type fracture (fan-like striations indicated by arrow) of undissolved carbides. This observation indicates that these particles would have accelerated growth of the fatigue crack by fracturing in a brittle manner on a single cycle of load over a distance much larger than the crack growth per cycle indicated by the very fine striations noted earlier.

Metallographic examination of an area adjacent to the void revealed interdendritic networks of undissolved carbide particles.

Container II

Revised Container-Assembly Design

Tooling components that are made from low-ductility materials and operate in service at low safety factors are prone to failure by low-cycle fatigue.(23, 48) The liner component is a case in point. To minimize possible problems with low-cycle fatigue, it was felt at the time that the service stresses should be held below the elastic limit, rather than below the 0.2 percent offset yield strength of the material. One of the problems, however, was the lack of adequate and reliable data on elastic limit and yield strength of AISI-M50 steel (liner material) in the hardness range of R_C 61 to 63. In the absence of such data, a minimum safety factor of 1.25 (based on best estimates of yield strength) was selected for the revised design to reduce the possibility of stressing the component above the elastic limit.

Changes in the container assembly design aimed at increasing the safety factor were necessarily limited to those which would keep fabrication costs to a minimum. Thus, possible design changes were narrowed to two options, both of which included use of the present sleeve and container components. In one design, use of a tungsten carbide liner was considered because of its high compressive yield strength. However, this design was eliminated because the difference in thermal-expansion coefficients between steel and carbide (6.5×10^{-6} versus 2.5×10^{-6} inch/inch/F) would cause the

FIGURE 71. ELECTRON MICROSCOPIC FRACTOGRAPH SHOWING FINE FATIGUE STRIATIONS IN LINER OF CONTAINER I

12,200X E1646A

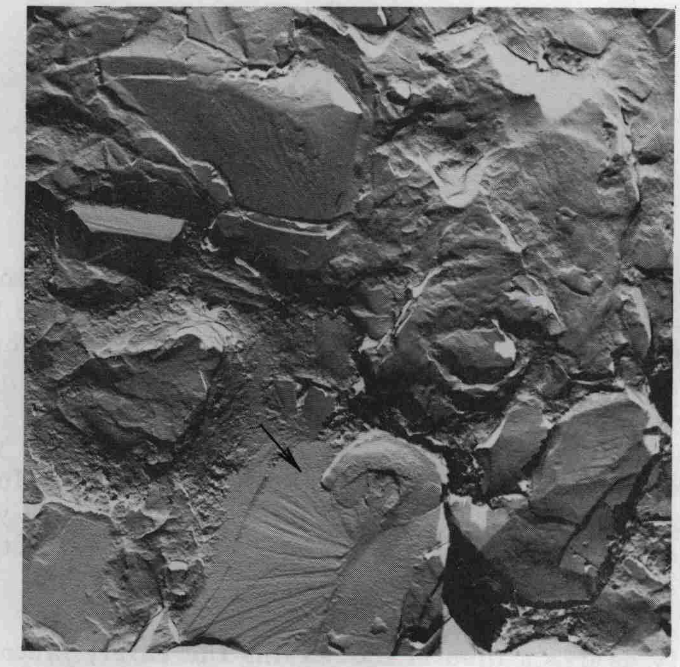

FIGURE 72. ELECTRON MICROSCOPIC FRACTOGRAPH SHOWING CLEAVAGE FRACTURE OF UNDISSOLVED CARBIDES IN LINER OF CONTAINER I

6,200X E1646E