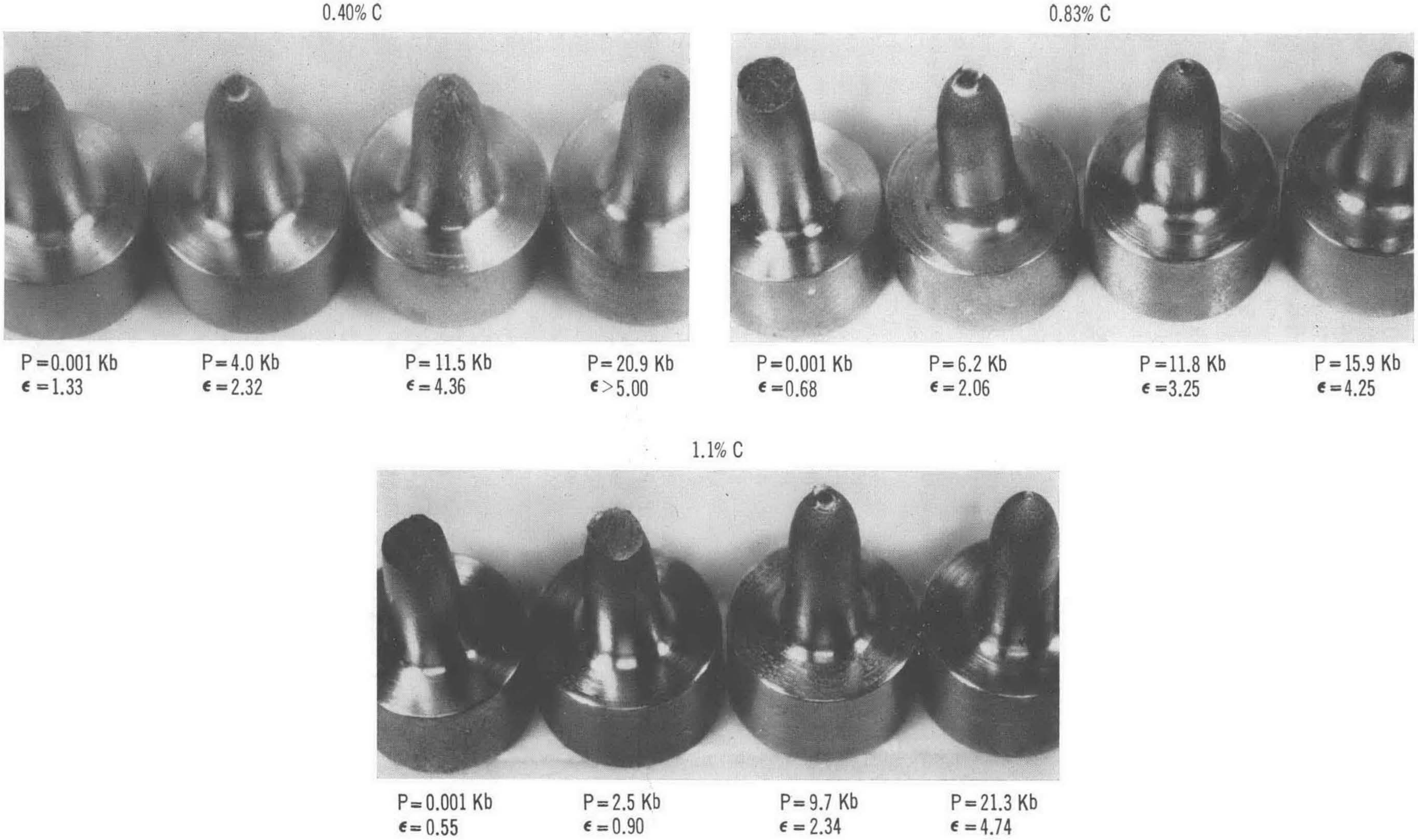

Fig. 8. Macroscopic fracture appearance as function of pressure in spheroidized Fe – C materials.

pressure retarded the brittle fracture mode, thus initially increasing the amount of uniform strain obtained prior to necking.

Relationship Between Pressure Coefficient of Ductility, β, and Strain Hardening Coefficient, n

The pressure coefficient of ductility, β as a function of the strain hardening coefficient n is shown plotted in Fig. 6 for the materials of this current investigation. It should be noted that in the case of the annealed 0.40, 0.83, and 1.1% C materials, β varied as a function of pressure as was previously discussed. However for comparison purposes, the pressure coefficient of ductility for the best fit linear relationship between strain to fracture and pressure for these three materials are the values plotted in Fig. 6.

As can be seen in Fig. 6, β generally increased with decreasing n. However, the relationship between β and n is not linear, which is in contrast to the proposal by Bridgman (1), and exhibits considerable structure sensitivity. The dependency of this relationship upon microstructure is particularly noticeable in the case of the 0.83 and 1.1% C materials. Whereas the value of β is dependent upon whether these materials are in the annealed or spheroidized condition, n is effectively the same for both conditions. Only if the data for the annealed 0.83 and 1.1% C materials are neglected is a near linear relationship between β and n obtained, as is shown by the solid line in Fig. 6.

It is apparent that the relationship between the pressure coefficient of ductility and strain hardening coefficient is significantly structure sensitive and, based on the materials investigated, is not linear. Apparently then, the considerable scatter in the results of Bridgman, particularly for plain carbon and low alloy steels, is a manifestation of his having a variety of different microstructures.

Effects of Pressure Upon Macroscopic Fracture Appearance

The macroscopic fracture appearance as a function of pressure is shown in Fig. 7 and 8 for the annealed and spheroidized materials, respectively. As can be seen in Fig. 7, the macroscopic fracture appearance for the annealed 0.004% C material changed from a cup-cone at atmospheric pressure to one exhibiting a point or "chisel" point at high pressure. Considerable ribbing also occurred. In the case of the annealed 0.40 and 0.83% C materials, as also seen in Fig. 7, the fracture at atmospheric pressure was cup-cone with the shear portion increasing progressively with increasing pressure at the expense of the fibrous (cup) region. At high pressure, the fracture converted to a planar shear type with the fracture surface being quite flat and oriented approximately along the shear plane. The annealed 1.1% C material exhibited a flat cleavage type of fracture at atmospheric pressure. With increasing pressure, the fracture progressively converted to a planar shear without any tendency toward a cup-cone type. At the highest pressure (22.8 kbars), the fracture was almost entirely planar shear with a thin peripheral ring of flat or cleavage type fracture. It can also be noted that in the necked region there were numerous fissures on the longitudinal surface.

In the case of the three spheroidized materials, as shown in Fig. 8, the change in macroscopic fracture appearance as a function of pressure was much the same as for the intermediate carbon annealed materials. The fracture exhibited an increase in the shear portion of the cup-cone type fracture with increasing pressure. At high pressure the fracture in all three materials converted to a planar shear type.

Considering the macroscopic fracture surface appearance, Bridgman reported a linear relationship between pressure and the ratio of tensile (fibrous) to total fracture area. His data, however, exhibited considerable scatter and it is questionable that such a relationship should actually exist.

Plotted in Fig. 9 is the ratio of fibrous to total fracture area as a function of pressure for the materials of this current investigation. The 0.004% C material is not shown, due to the inability of accurately defining the fibrous fracture region because of irregular fracture profile and ribbing. The 1.1% C material is also not shown since, as previously demonstrated, it did not exhibit a cup-cone fracture but went directly to planar shear from a flat cleavage type fracture.

As can be seen in Fig. 9, there is no linear relationship obtained if a best fit curve is used. The scatter would be so great that any attempt toward a linear fit is evidently illogical. As is evident, the curves are of the same general form for all materials. There is an initial rapid decrease in the fracture area ratio with increasing pressure, followed by a leveling off in the range of an area ratio of 0.2 to 0.3. This leveling off, or plateau, which exists over a significant pressure range, is then followed by an abrupt decrease in area ratio over a narrow pressure range in which the area ratio goes to zero. This form of curve is most evident in the annealed and spheroidized 0.83% C material. There is no systematic variation in the form of the curves with respect to material or structure except that the pressure at which the fracture converted completely to planar shear generally increased with increasing strength.

A possible reason for the lack of a continuous relationship between the ratio of fibrous to total fracture area and pressure is that the basic fracture mechanism at atmospheric pressure may be the same for both the fibrous and shear portions of the cup-cone fractures exhibited by these materials. Pressure may, therefore, affect the fracture mode in both of these regions (9). Thus, pressure may not increase the amount of the shear fracture of the type characteristic at atmospheric pressure, but may cause the