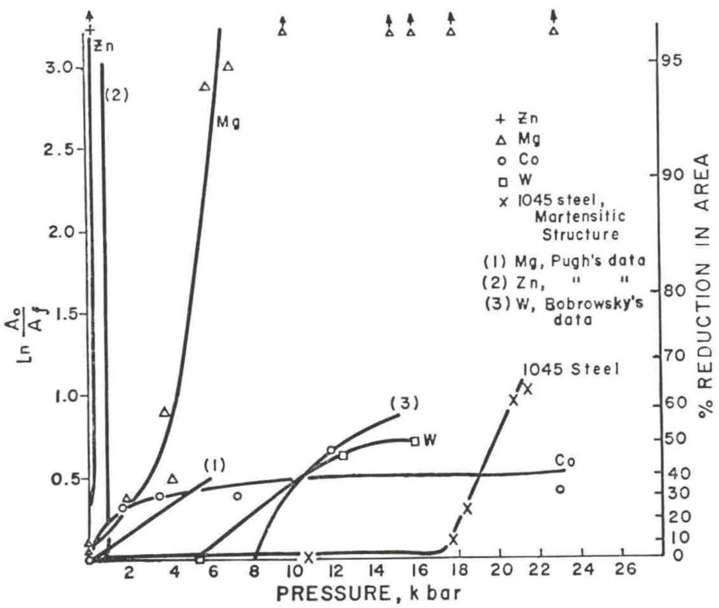

FIG. 2. Effect of pressure upon the ductilities of various metals.

The metallographic preparation of the fracture surfaces of magnesium was standard except for the vapor deposition of a layer of chromium on the fracture surface to prevent edge rounding. Mechanical polishing was used. The etchant consisted of 20 parts acetic acid, 60 parts ethyl glycol, 1 part nitric acid, and 19 parts distilled water.

RESULTS AND DISCUSSION

Effects of pressure on ductility

Ductility in terms of natural strain to fracture and reduction in area as a function of pressure at ambient temperature is summarized in Fig. 2 for the metals investigated. In the case of zinc, an abrupt brittle–ductile transition occurred at 0.1 kb where the ductility increased from 23 to 100% reduction in area. In comparison, Pugh observed the occurrence of the transition at 1 kb. The difference between the two results can be readily accounted for by the lower purity (99.8%) material used by Pugh as compared to that of the current investigation.

Initially, magnesium showed a nearly linear region and then a sudden increase in ductility to effectively 100% at 4 kb. In comparison, Pugh observed a linear region up to 6 kb although it is likely that he would have observed a similar transition in ductility had he gone to somewhat higher pressures. The difference in results may be attributable to a large difference in grain size and processing history.

Both tungsten and 1045 steel exhibited similar results consisting of a pressure insensitive region with an apparent brittle–ductile transition at 6–10 and 17 kb respectively. A similar observation for tungsten was recently reported by Bobrowsky.[6]

In contrast to the other metals, cobalt exhibited an initial increase in ductility up to 4 kb with no further pressure effect up to 23 kb.

Figure 3 summarizes the effects of pressure upon the ductility of magnesium at several temperatures. Each curve shows an initial region over which the ductility increases somewhat linearly with pressure until a point is reached at which the ductility goes effectively to 100% over a narrow pressure region. The relationship, if any, between this type of pressure-induced brittle–ductile transition and the commonly known temperature-induced transition at atmospheric pressure is currently under investigation and will be reported separately.

Macroscopic fracture appearance

Among the metals investigated, steel, cobalt and tungsten exhibited a planar or flat type of brittle fracture at atmospheric pressure, and a cup–cone type at high pressure. In terms of the nomenclature in Table 1, the flat portion of the cup–cone is fibrous or a combination of fibrous fracture and cleavage, and the inclined portion shear type ductile fracture. With increased pressure, the area of the fibrous fracture decreased with an associated increase in ductility, which is consistent with the proposed model. Zinc necked to a point above the transition pressure. In contrast, magnesium exhibited a drastically different behaviour. However, since magnesium was studied in great detail, its macroscopic fracture appearance will

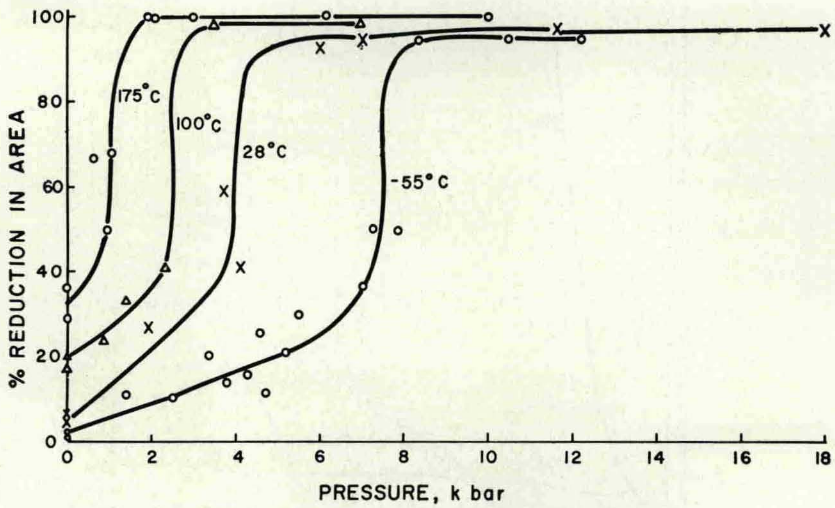

Fig. 3. Effect of pressure upon the ductility of magnesium at various temperatures.

be subsequently described in conjunction with the observed effects of pressure on fracture mechanism.

Fracture of magnesium

Atmospheric pressure. The macroscopic and microscopic fracture characteristics of magnesium at atmospheric pressure and various temperatures are shown in Figs. 4 and 5 respectively. The macrofracture appearance is brittle at low and ambient temperatures, progressively changing to a ductile rupture at higher temperatures. The associated ductility increased continuously with no apparent brittle–ductile transition over the temperature range of −55°C to 175°C. The microstructure in a plane parallel to the tensile axis, as shown in Fig. 5, shows predominantly intergranular fracture at −55°C with lesser amounts at room temperature, which is in agreement with the results of Hauser *et al.*[13] One can readily see the intergranular fissures which formed behind the fracture surface particularly at −55°C. At 70°C, voids started to form which increased in size and propensity at 175°C. As is typical of high temperature rupture, these voids formed at grain-boundary triple-points and grew into spherical

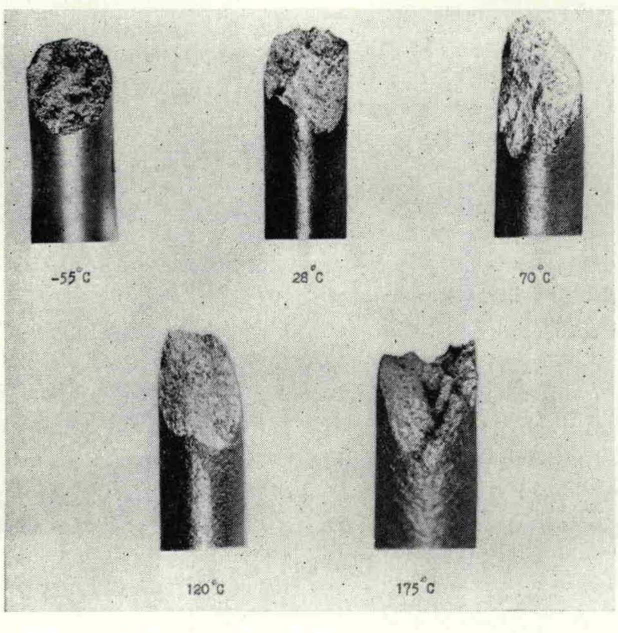

Fig. 4. Fracture appearance of magnesium as a function of temperature at atmospheric pressure.