ABSTRACT

It is well documented that the ductility of even quite brittle materials can be enhanced if they are deformed under a superposed hydrostatic pressure of sufficient magnitude. The ability to enhance ductility by a superposed hydrostatic pressure is of considerable practical significance and has become the basis for a new family of metal forming processes. One such process is hydrostatic fluid extrusion.

Using a hydrostatic fluid extrusion process, it has been possible to sucessfully cold reduce a variety of high strength materials that, as a result of their strength level and low ductility, could not be deformed by conventional means. The techniques used and the typical results for such materials as T. D. Nickel, Maraging Steel, Nickel-base superalloys and carbon steels in the untempered martensitic condition will be presented.

Of equal importance to the ability of cold reducing such materials is the effect of cold reduction by fluid extrusion upon the subsequent mechanical properties. The significant increases in strength achieved over the conventional properties with little or no change in ductility will be described and discussed.

INTRODUCTION

The effects of high superposed pressure upon the mechanical properties, particularly ductility, of metals has long been of interest. In fact, since the work of VanKarman(1) in 1910, it has been known that the ductility of even the most brittle materials is enhanced if they are deformed while under a superposed pressure of sufficient magnitude. The effects of superposed pressure upon the tensile ductility of a variety of metals have been measured by several investigators.(2)(3)(4)(5) Typical results from these investigations are shown in Figure 1. As can be seen, the type of the ductility-pressure relationship varies considerably between materials ranging from linear for mild steel and cast iron to a brittle-ductile transition behavior in the case of zinc, bismuth, magnesium, tungsten and untempered 4145 steel.

The form of the ductility-pressure curve has been found to be not only affected by the material, but is also structure sensitive and depends upon the condition of heat treatment. Figure 2 shows the form of the ductility-pressure curves for a series of iron-carbon alloys in two conditions of heat treatment.(6) As can be seen, the materials fall into two categories. The 0.004% C and the spheroidized materials, wherein the cementite is in the form of isolated spherical particles in a ferrite matrix, exhibit a linear ductility-pressure relationship with the slope decreasing with increasing carbon content. In the case of the three annealed materials, wherein the cementite is in the form of closely spaced platelets (pearlite) or as a continuous network along prior austenitic grain boundaries, the ductility-pressure relationship is non-linear.

The ability to enhance ductility by pressure is of considerable practical significance and has become the basis for a new family of metal forming processes. One such process is hydrostatic fluid extrusion. Figure 3 compares, in schematic fashion, hydrostatic fluid extrusion and conventional extrusion apparatus. It should be noted that in the hydrostatic fluid extrusion technique the uniaxial ram force of the conventional extrusion technique is replaced by a hydrostatic pressure. The advantages of this technique are to reduce the frictional forces between the billet and the containing vessel and exploit the enhancement in ductility of the deforming billet by the superposed hydrostatic pressure. Accordingly, this technique offers the ability to cold deform a variety of materials previously considered not deformable.

For extremely brittle materials and/or for high reductions, it is possible to further exploit the pressure enhanced ductility of metals by utilizing a fluid to fluid technique. This technique is compared schematically to normal hydrostatic extrusion in Figure 4. With this technique the deforming material leaves the high pressure chamber and enters a pressure chamber of lower hydrostatic pressure; the pressure in this chamber being greater than one atmosphere. Since the pressure differential must remain essentially constant for a given extrusion application, the presence of a high hydrostatic pressure at the die exit necessitates a higher forward pressure. Accordingly, the billet material is inherently more ductile because it deforms at a higher mean pressure.

Using a hydrostatic fluid extrusion process, it has been found possible to successfully cold reduce a variety of high strength materials which, as a result of the strength level and inherently low ductility, could not be deformed by conventional processes. It is the objective of this paper to describe the techniques used and the typical mechanical response for such materials as T.D. Nickel, nickel-base superalloys, maraging steels and low carbon alloy steels in the untempered martensitic condition.

EXPERIMENTAL PROCEDURES AND MATERIALS

Equipment

A schematic of the fluid extrusion system utilized in these investigations is shown in Figure 5 and a photograph of the apparatus in Figure 6. The system, as shown in Figure 5, is composed of three main segments consisting of an extrusion pressure chamber, extrusion die and die support, and an exit pressure chamber. The extrusion pressure chambers are joined by the die support.

The high pressure chamber consists of a one inch internal bore diameter. The tapered cylinder or liner of 250 grade maraging steel mates with the tapered support ring of AISI 4340 steel. Pressure is generated by means of the 188-ton jack which forces a tungsten carbide piston into the chamber. The pressure capacity of the billet chamber is 450 ksi. To prevent plastic flow or fracture of the liner at this pressure level, the tapered liner is forced into the matching tapered jacket by means of the 750-ton jack. In this manner, the stresses in the liner are progressively counteracted by increasing the 750-ton jack pressure as the billet chamber pressure is increased.

The exit chamber consists of a 3/4 inch internal diameter 250 grade