maraging liner with an AISI 4340 steel jacket. Back pressures up to 300 ksi can be developed by the 70-ton jack which forces a piston into the chamber.

The extrusion die and die support are fabricated of a 350 grade maraging steel. The extrusion die has a 45^{o} included entrance angle.

Schematic representations of sealing arrangement for the extrusion die is shown in Figure 7.

Materials

The chemical composition of the materials used for this investigation is shown in Table I. All the materials were in the wrought condition except INCO 713LC which was in the cast form and one form of the T.D. Nickel which was in the pressed and sintered condition.

The mechanical properties of the nickel-base superalloys and T.D. Nickel were determined using an 0.125 inch diameter, 0.500 inch gage length tensile specimen utilizing a strain rate of 0.005 in/in/min. Standard 0.252 tensile specimens were used for the 18 Nickel maraging and low carbon martensitic steels utilizing the same strain rate.

Extrusion Procedure

Each of the extrusion billets was machined to the diameter necessary for the desired reduction. The length of each billet was four inches and a 45^{o} included angle was machined on the forward end to match the extrusion die angle. Each billet was then sandblasted and coated with either Emerlon 323 (for use up to pressures of 230 ksi), a resin bonded colloidal teflon or a baked teflon coating (for use at pressures greater than 230 ksi). The pressure medium was either caston oil (less than 230 ksi) or a mixture of 75% glycerine and 25% ethylene glycol (greater than 230 ksi).

RESULTS AND DISCUSSION

T.D. Nickel

No difficulties were encountered in cold extruding commercial T.D. Nickel to reductions of 78% R.A. by hydrostatic fluid techniques. The room temperature tensile mechanical properties of this material at various reductions are shown in Table II. It should be noted that the strength was significantly improved with a corresponding slight improvement of ductility as a result of the cold reduction.

In addition, a comparison of hot tensile mechanical properties of the as-received and cold worked (78% R.A.) materials was made at a test temperature of $1600^{o}F$. As can be seen in Table II, the mechanical properties were found to be essentially equivalent since any increase in strength due to strain hardening would be reduced by annealing effects.

It was also attempted to extrude T.D. Nickel in the pressed and sintered condition directly into a usable product. For this purpose, the pressed and sintered compact was fitted into a hollow container which had been machined to the shape of an extrusion billet.

Some difficulties in the form of transverse cracking were encountered by extrusion of the pressed and sintered T.D. Nickel billets. The cracking problem was eliminated when a back pressure of 90 ksi was used in the exit chamber. A comparison of the two techniques is shown in Figure 8. The sound product was extruded using the 90 ksi back pressure. Table II shows the mechanical properties of the pressed and sintered T.D. Nickel compacts. It should be noted that at a reduction of 78% R.A., the properties are essentially identical for both the conventionally processed material and the material extruded directly from the pressed and sintered condition.

Maraging Steels

The reductions investigated and the nominal extrusion pressures required for the maraging steels studied are summarized in Table III.[7] It should be noted that in the case of the 250 and 350 grade maraging steels extruded in the solution-treated and aged condition, reductions of 65% R.A. and 25% R.A. respectively were obtained. Reductions of up to 50% were also accomplished in the 250 grade steel in the solution-treated condition. Much higher reductions are possible, but for this investigation such reductions were not required.

To investigate the necessity to use hydrostatic fluid extrusion to plastically deform high-strength materials such as maraging steels, the hydrostatic extrusion press was modified to do conventional extrusion. Figure 9 compares the extruded product of both conventionally and hydrostatically extruded 250 grade maraging steel in the fully heat treated (solution treated plus aged) condition. It is clearly shown that these materials cannot be plastically deformed to large reductions at room temperature without massive cracking of the extruded product.

The effects of cold reduction by extrusion on the tensile mechanical properties of 250 grade maraging steel extruded in the solution-treated, and solution-treated and aged condition and post-aged condition after extrusion in the solution-treated and aged condition are seen in Figures 10, 11 and 12, respectively. It should be noted that, in general, the strength increases and the ductility remains essentially constant with increasing amounts of cold work. The greatest increase in strength (77 Ksi) was achieved when the material was extruded in the fully heat-treated condition followed by re-aging (Figure 13).

Figure 13 shows the effect of cold deformation by hydrostatic fluid extrusion on the tensile mechanical properties of 350 grade maraging steels in the fully heat-treated condition. Again, the strength increased with no loss in ductility.

Nickel-Base Superalloys

Table IV shows the effect of cold reduction on the mechanical properties of several nickel-base superalloys.[8] It is of importance to note that in all cases the cold reduction had a considerable effect on enhancing the strength of already high strength materials. This strength increase was due to strain hardening in combination with enhanced secondary precipitation during the re-aging treatment.

The effects of cold reduction on ductility tended to vary widely between materials. Rene 41 exhibited no significant ductility change. The Inconel 718 exhibited a ductility decrease, but, considering the strength increase, it is not deemed too serious. The Udimet 630 alloy lost significant ductility whereas the as-cast INCO 713LC actually increased