Group 4: The rods in this group have a beta microstructure; however, the rods have circumferential cracks. These cracks presumably occurred during extrusion, when sharp variations in extrusion pressure were noted. The circumferential cracks have the characteristic appearance known as a "rattlesnake" defect in extruded shapes.

4. Discussion

The observed structures and textures can be interpreted as consequences of the extent to which the uranium transforms into the beta phase during or after extrusion. The extrusion work can raise the temperature of the uranium above the normal transformation temperature (663° C). Since the transformation temperature is increased by pressure, the extruding uranium can remain in the alpha phase until it leaves the die land. There the uranium transforms into the beta phase, acquiring a random texture and a grain size determined by the rate of cooling from the beta.

The extent of transformation into the beta depends on the severity of the extrusion conditions: initial billet temperature and strain rate (reduction and ram speed). If these conditions are severe enough for complete transformation to occur *after* extrusion, only beta structure is obtained. If the extrusion conditions are so severe as to permit some transformation even *during* extrusion, rattlesnaking results (Group 4). The alpha structures of Group 2 reflect mild extrusion conditions. The Group 3 structures (beta core with alpha rim) are produced by conditions that facilitate cooling of the billet surface while beta temperatures are attained in the core.

A beta-structure rod fast cooled after it leaves the die tends to acquire the fine grain size imparted by a quench after conventional beta treatment. Rods 11 and 12, which were air-cooled, had grains larger than 1000 μm. The smallest grains were found in rods that had been sprayed with water as they left the die. However, in rods 3 and 9, the grain size was 750 and 1000 μm respectively, in spite of the water spray. This large grain size was probably caused by a delay in turning on the spray device, which was hand-operated on a signal from the press operator.

A drastic quench produces radially columnar grains near the surface (rods 6, 7 and 8). These rods had a texture with a concentration of {010} poles *parallel* to the rod axis, giving a positive GI_L. This texture is unusual for uranium extruded at high temperatures in the alpha phase; under these conditions {010} poles usually are *perpendicular* to the rod axis. Work at another laboratory [6]) has shown that alpha grains formed in a steep thermal gradient grow in a columnar fashion with the {100} poles aligning themselves in the direction of the thermal gradient. The {010} axial texture in the quenched rods may thus be a consequence of the {100} radial texture. The unusual direction of the {010} poles in the quenched rods is thus attributed to the effect of the steep radial temperature gradient during quenching.

The grains of "beta structure" rods can also be refined by alloying as is illustrated in the small grain size (50 μm) of uranium-0.16 wt % silicon nos. 4 and 5 compared to the larger grain size (750 μm) of unalloyed rod no. 3 extruded under the same conditions. The thickness of the fine-grained rim can be controlled by cooling the rim of the billet before extrusion. Two billets (rods 20 and 21) were extruded in tandem in a cool extrusion container (250° C). The rear billet was in contact with the cool extrusion container for 3 sec longer after the extrusion upset than was the front billet. The thickness of the fine-grained rim on the rear rod was approximately twice the thickness of the fine-grained rim on the front rod (fig. 1).

5. Summary and conclusions

Extrusion conditions can be selected so that an extruded uranium rod transforms to the beta phase as it leaves the die and thereby acquires a structure that ordinarily is achieved