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STRENGTH DIFFERENTIAL EFFECT IN α -PLUTONIUM

M. D. Merz

This note is a report of the strength differential effect (S-D effect) in monoclinic α -plutonium. The difference in tensile and compressive strengths was studied at strain rates from 8.3×10^{-3} to $6.7 \times 10^{-5} \text{ sec}^{-1}$ at 22 to 100°C. A significant increase in σ_t/σ_c , the ratio of tensile to compressive stress, from 0.62 to 0.92, was observed as temperature increased; a similar increase was observed with decrease in strain rate at 100°C.

High purity electrorefined plutonium was extruded to minimize the effects of microcracks which are always present in as-cast high purity metal.⁽¹⁾ This was necessary to attain reproducible tensile elongations, especially at the lower testing temperatures. Specimens for the tensile tests were cylindrical with 0.50 inch (1.25 cm) gage length and 0.20 inch (0.50 cm) diameter. The compression specimens were also cylindrical with 0.40 inch (1.0 cm) gage length and 0.20 inch (.50 cm) diameter. Some contribution to the difference in tensile and compressive strength at the same crosshead speed was attributed to the gage length difference. The ratio σ_t/σ_c can be corrected for this by a factor $[0.5 \exp(\epsilon)]^{.24}/[0.4 \exp(-\epsilon)]^{.20}$ equal to 1.02 for $\epsilon = 0.01$, and 1.06 for $\epsilon = 0.1$, since the relation $\sigma = K\epsilon^m$ was obeyed over the stress range reported here, $m \approx .24$ for tension⁽²⁾ and $m \approx 0.20$ for compression.

The difference in tensile and compressive yield stress (1% offset) was 46,000 psi at 22°C and 0.002 in/min., Figure 1, Table I. A large difference in flow stress persisted over the entire stress strain curve. With increased

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TABLE I
TENSILE AND COMPRESSIVE FLOW STRESSES FOR α -PLUTONIUM

Temp	Crosshead Speed (in/min)	Tension		Compression		$\frac{\sigma_t}{\sigma_c}$ at 1%	$\frac{\sigma_t}{\sigma_c}$ at 10%
		1% Flow Stress (psi)	10% Flow Stress (psi)	1% Flow Stress (psi)	10% Flow Stress (psi)		
22°C	0.002	62,500	*	108,000	99,500	0.58	*
60°C	0.002	32,000	35,000	48,500	56,000	0.66	0.87
60°C	0.02	51,000	*	78,000	76,400	0.65	*
60°C	0.2	83,500	*	112,000	93,500	0.75	*
100°C	0.002	12,000	13,000	13,000	16,000	0.92	0.81
100°C	0.02	21,000	22,000	23,500	30,500	0.89	0.72
100°C	0.2	37,000	34,000	55,000	58,000	0.67	0.59

* Tests where tensile elongation was less than 10%.

temperatures, at the same rate, the strength differential decreased, Table I, Figure 2. However, at the highest testing speed, 0.2 in/min., the effect was still appreciable at 100°C, Table I, Figure 3. The apparent decrease in tensile stress beyond about 0.2 strain was attributed to gradual necking of the specimen.

Several possible causes for the strength differential in steels and cast iron have been reported, including transformation of retained phases, opening of microcracks, residual stresses, internal baushinger effect and nonlinear solute-dislocation interactions.⁽³⁾ Some of these are reasonably ruled out for α -plutonium. Retained phases are negligible in the extruded α -plutonium; moreover such phases would transform more readily under compressive stress than under tensile stress. Residual stresses due to deformation and phase transformation damage were very small as evidenced by very sharp x-ray diffraction peaks from extruded α -plutonium, and such stresses could not be expected to have an effect beyond a few percent strain. The effect of impurities has not been investigated, though the total impurity content of the metal used was quite low, about 300 ppm. Microcracks are present in the microstructure of as-cast α -plutonium but after extrusion do not appear to affect the properties. No cracks were visible in the microstructure at 1000X; however, the cracks are probably elongated beyond recognition by the extrusion process and are probably aligned with the major crack surface parallel to the tensile and compressive stress axis. Such alignment minimizes the effect of cracks on tensile and compressive properties. Examination of fracture surfaces by scanning electron microscopy after fracture at -196°C and 22°C indicated no opening of such cracks during deformation. Thus, the observations on α -plutonium do not support any of the proposed explanations for the SD effect.

Microstructural changes during deformation were significantly different for tension and compression. In compression the grain size became larger in the center of the specimens where the strain was highest; there was a corresponding hardness increase as expected from a previous study on hardness-grain size dependence in alpha plutonium.⁽⁴⁾ However, in tension no grain size increases were observed; only disappearance of some of the larger grains present before testing. These observations may be a secondary effect due to differences in flow stress for compression and tension but do suggest that recrystallization and/or grain growth may be important factors in the SD effect in α -plutonium.

The effect of crystallographic texture may have bearing on the SD effect in α -plutonium. The extruded plutonium had a strong fiber texture with the (020) planes normal to the stress axis applied during testing. Texture can affect the incidence of mechanical twinning, which has been reported to occur to a limited extent in random oriented α -plutonium.⁽⁵⁾ Twinning as a deformation mode can depend on the sense of the shear stress relative to crystallographic directions as pointed out for zinc⁽⁵⁾ and marble⁽⁷⁾ and might be favored by a tensile stress normal to (020) planes compared to compressive stress normal to the same planes. Further tests on randomly oriented specimens and transverse tests on textured specimens will hopefully resolve this point.

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FIGURE 1. TENSION AND COMPRESSION TRUE STRESS-STRAIN CURVES FOR α -PLUTONIUM AT 22°C, CROSS HEAD SPEED = 0.002 IN/MIN

FIGURE 2.. TENSILE TO COMPRESSIVE STRESS RATIO VERSUS
TEST TEMPERATURE AT INDICATED CROSSHEAD SPEEDS

FIGURE 3. TENSION AND COMPRESSION TRUE STRESS-STRAIN CURVES FOR α -PLUTONIUM AT 100°C, CROSSHEAD SPEED = 0.2 IN/MIN

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