Plasticity of monocrystalline yttrium oxide (Y_2O_3) at 0.45 T_m

In recent years there has been increasing interest in yttrium oxide (Y_2O_3) as a highly refractory ceramic (melting point $T_m = 2450°$ C). The crystal structure of Y_2O_3 is of the rare earth sesquioxyde C type in which each Y^{3+} ion is surrounded by six oxygen anions located at the corners of a cube. The space group is Ia_3 (Th 7). Hitherto only a few studies concerned with the plastic deformation of polycrystalline Y_2O_3 have been available in the literature [1]. None have been carried out on the monocrystalline material. The aim of this letter is to give some preliminary results of plastic deformation tests carried out by compression.

Monocrystalline samples of dimensions 5 mm x 2 mm x 2 mm were obtained by the Verneuil method. The compressive experiments were performed on an Instron testing machine using a high temperature equipment [2] which is capable of operating in several environments, i.e., air vacuum or inert gas up to 1750° C. As Y_2O_3 is a stable oxide, tests were conducted in air. Creep tests were carried out at high temperatures [3] (1600 to 1800° C) using a classical creep testing machine, as yttrium oxide is creep resistant ($\dot{\epsilon}$ steady state = 5.5 10^{-7} sec^{-1} for $\sigma \sim 80$ mPa at 1800° C). In order to minimize a major contribution of dislocation climb, tests were conducted at 0.45 T_m ($\sim$ 1120° C). The stress was applied at a low velocity ($\dot{\epsilon}_e = 4 \times 10^{-6}$ sec^{-1}). When the load reached 1.57 x 10^3 N, corresponding to an engineering stress of 400 MPa on the sample, the cross-head was then controlled to allow the Instron to operate as a creep testing machine. This experimental process was used because of the brittleness of the sample at temperatures lower than 0·5 T_m. Deformation of the specimen was measured with a linear differential transducer device and recorded continuously as a function of time. Two single crystals with different orientations were studied. The first sample had a $\langle 0\,0\,1 \rangle$ compression axis with four $\{0\,0\,1\}$ faces. The second one had a $\langle \bar{1}\,1\,0 \rangle$ compression axis and faces $\{1\,1\,1\}$ and $\{1\,1\,\bar{2}\}$

The results of the study are given below.

(1) Single crystal with $\langle 0\,0\,1 \rangle$ compression axis: the true strain–time curve is shown in Fig. 1. This curve is composed of two different parts, the first being for deformation induced at a constant strain rate ($\dot{\epsilon}_e$). The corresponding strain is almost elastic. The second region shows a classical strain–time

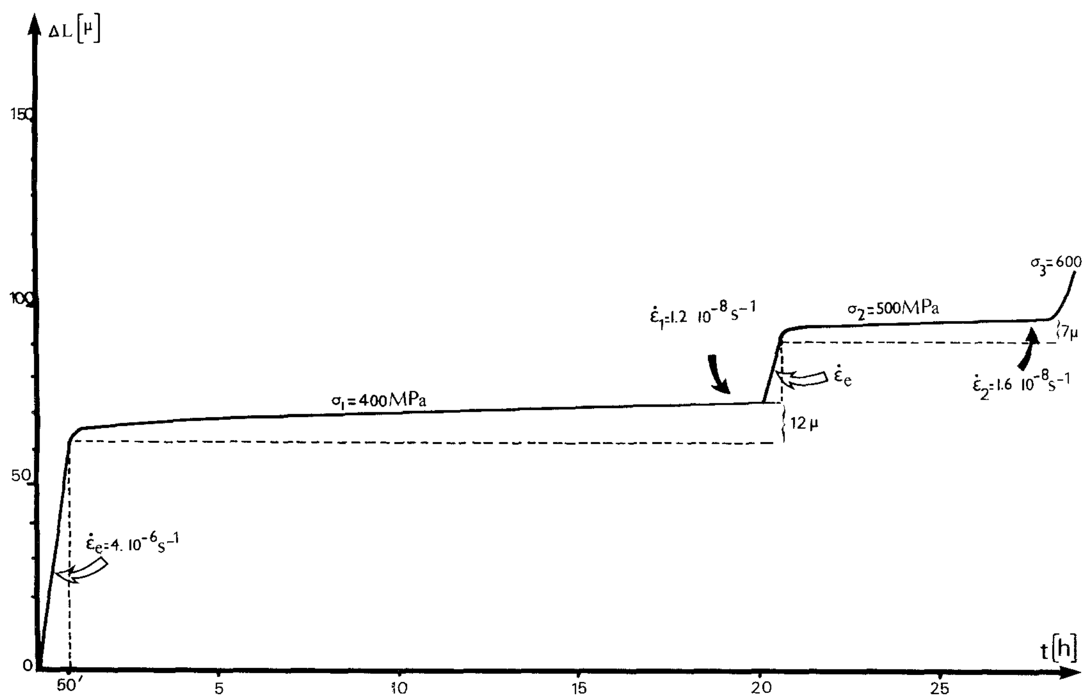

Figure 1 Strain–time curve for a single crystal with a $\langle 0\,0\,1 \rangle$ compression axis. Arrows indicate deformation induced at constant strain rate ($\dot{\epsilon}_e = 10^6$ sec^{-1}).

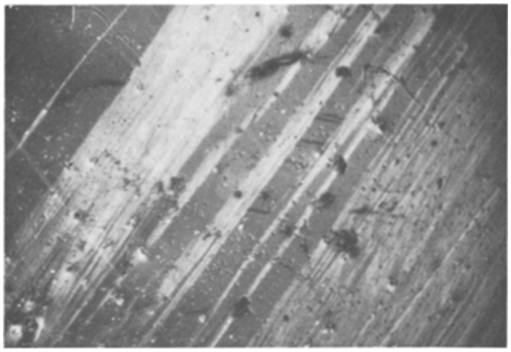

Figure 2 Single crystal with a ⟨0 0 1⟩ compression axis. The face shown is the (1 0 0) face with glide lines corresponding to the {1 1 0} glide plane.

creep behaviour. Plastic deformation was achieved in this sample with loads up to 2.35 10^3 N (a stress of 600 MPa on the sample). Under this stress, cracks began to propagate. Compressive strain measured on the chart trace, corresponding to the creep part of the strain–time curve, is identical to the deformation undergone by the sample. A stress increment was achieved of $\Delta\sigma = 100$ MPa and a value of the ratio $n = \text{Log}(\dot{\epsilon}_2/\dot{\epsilon}_1)/\text{Log}(\sigma_2/\sigma_1) = 1.6$ was obtained. The lowest strain rates registered were $\epsilon_1 = 1.2 \times 10^{-8}$ and $\dot{\epsilon}_2 = 1.6 \times 10^{-8}\ \text{sec}^{-1}$, corresponding to $\sigma_1 = 400$ and $\sigma_2 = 500$ MPa respectively. As the glide planes of this structure were unknown, the faces of the single crystal were examined thoroughly with an optical microscope using a Normarski interferential contrast device. The results are shown in Fig. 2. A study of the four faces gives evidence of (1 1 0) glide planes only. This result was expected as the shortest Burgers vector of the structure $\mathbf{b} = a/2\langle 1\,1\,1\rangle$ belongs to those planes.

(2) Single crystal with $\langle\bar{1}\,1\,0\rangle$ compression axis and faces {1 1 1} and $\{1\,1\,\bar{2}\}$: in order to study the orientation dependence of the plastic behaviour, the above orientation was tested. Measurable strain was not achieved as the fracture had appeared before a sufficient amount of plastic deformation had taken place. The test was stopped at 200 MPa. Nevertheless, examination of the sample faces showed evidence of plastic deformation (Fig. 3). Indexing the lines on the different faces indicates (1 0 0) deformation planes. This result is quite surprising as {1 0 0} planes do not contain the shortest Burgers vectors of the Y_2O_3 structure and cannot be explained by the Schmidt factor on the slip system since $\{1\,0\,0\}\langle 0\,0\,1\rangle \rightarrow 0.5$ and $\{1\,1\,0\}\langle 1\,\bar{1}\,1\rangle \rightarrow 0.4$, which are not very different. This experimental result may be related to recent theoretical calculations [4] which have shown that there is lower stacking fault energy in the {1 0 0} planes than in other planes.

Experiments performed at higher temperatures [3] ($\simeq 1800°$ C) confirm this result. Laue diagrams and electron microscope investigations have never shown evidence of mechanical twinning. From these preliminary results it is concluded that yttrium oxide can be plastically deformed under $0.5\,T_m$ provided that the loads are large enough and applied on the specimens in order to avoid catastrophic fracture. The expected {1 1 0} glide plane is found. Furthermore, the {1 0 0} planes seem to play an important role in the plastic properties of this oxide.

Figure 3 Single crystal with a ⟨1 1 0⟩ compression axis. The face shown is the (1 1 1) face, with glide lines corresponding to {1 0 0} glide planes. The arrow indicates a crack.

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