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Effect of Temperature on the Mechanical Properties of Solid Pressure-Transmitting Media. I. Talc

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High-temperature compression tests have revealed unsuspected high-temperature strength in block talc. Analyses by x-ray diffraction indicate that the increase in strength is associated with the transformation of the talc to protoenstatite, silica, and water. The bulk modulus of elasticity also increases with increasing temperature, reaches a maximum at 1100°C and then decreases at higher temperatures. These findings suggest that block talc is not as suitable for a solid pressure-transmitting medium at elevated temperatures as is commonly supposed.

INTRODUCTION

THE advent of utilizing solid pressure-transmitting media has made available new areas for high-pressure-high-temperature experimentation, even though the data obtained are not as accurate as those measured at lower pressures using other media. Many pressure data which have been reported are based on room-temperature calibration curves constructed by the standard techniques.^{1,2} Such measurements are considered to have some validity at high temperatures based on the assumption that the solid pressure-transmitting media decrease in strength with increasing temperatures.^{1,3} However, there are apparently few data available concerning the effect of temperature upon the mechanical properties of solid pressure-transmitting media.

The materials which are most widely used as solid pressure transmitting media are talc and pyrophyllite. Talc, which is used principally in piston-cylinder devices, has been preferred over pyrophyllite for this application because it transmits pressure more efficiently,^{1,2} and therefore provides more pressure on the

sample for a given applied load. At elevated temperatures the situation is complicated by the transformation of the talc to protoenstatite, silica, and water. Moreover, because of the thermal gradients that exist in high-pressure devices, the extent of the transformation varies throughout the talc cylinder from a maximum at the surface near the heater to no reaction at the outer surface. The confined water vapor may also have some effect on the high-temperature strength of the components in the high-pressure cell.

The present study was undertaken in order to investigate the effect of temperature upon the strength and ductility of block talc, particularly at temperatures where the talc begins to transform to protoenstatite, silica, and water. In addition, the talc was characterized by room-temperature testing of fired samples, volume change, and weight loss measurements. X-ray diffraction, electron microscope, and differential thermal analyses were also utilized in this investigation.

EXPERIMENTAL PROCEDURE

The block talc used in this investigation was obtained from the American Lava Corporation and has their designation of Lava Grade 1136. The test specimens were machined into the shape of cylinders 0.500 in.

¹ F. R. Boyd and J. L. England, *J. Geophys. Res.* **65**, 746 (1960).

² J. E. Tydings and A. A. Giardini, ASME Preprint 62-WA-307, presented at the Winter Annual Meeting, New York (1962).

³ F. R. Boyd and J. L. England, *J. Geophys. Res.* **68**, 312 (1963).

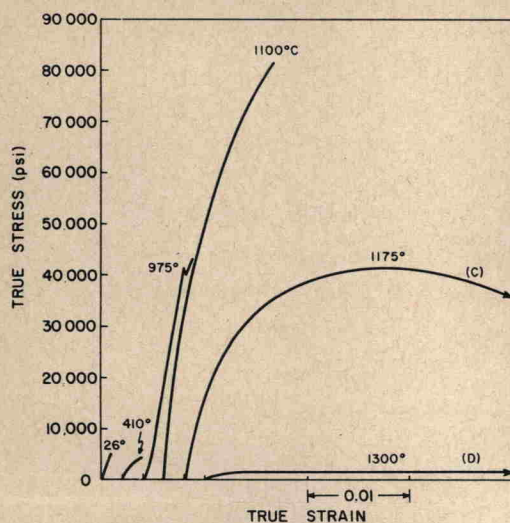


Fig. 1. Typical stress-strain curves of talc in compression at different temperatures.

(1.27 cm) in diameter by 1.125 in. (3.18 cm) long and their ends polished so as to be perpendicular to the axis of the cylinder. The compressive tests were performed using a Tinius-Olsen Universal Testing machine equipped with alumina rams having alumina pads inserted between the talc specimens and the rams in order to prevent damage to the rams from glassy phases formed in the pryophyllite upon firing. A furnace with silicon carbide heaters was used to heat the talc and rams at a rate of 6° to 10°C/min. The specimens were held at the test temperature for 30–50 min, and then tested in compression at a strain rate of $1 \times 10^{-3} \text{ min}^{-1}$. Temperatures were measured with a platinum-platinum 10% rhodium thermocouple whose exposed hot junction was next to the specimens. Typical true-stress versus true-strain⁴ curves of talc in compression at different temperatures are shown in Fig. 1, while the ultimate stress and strain in compression versus temperature are shown in Fig. 2. The stresses were calculated using the original cross section of the specimen prior to firing. In the case of the fired specimens which were tested at room temperature (Fig. 4), the firing treatment was similar to that experienced by the specimens which were tested at high temperature.

RESULTS AND DISCUSSION

As shown in Figs. 1 and 2, the compressive strength of talc begins to increase at about 800°C, reaches a maximum at about 1100°C, and then decreases at higher temperatures. The increase in strength with increasing temperature approximately coincides with the development of protoenstatite⁵ in the talc. For example, in Fig. 2, specimen A whose x-ray diffraction

pattern indicated the presence of only a small amount of protoenstatite had an ultimate strength of 20 000 psi (1400 kg/cm²), more than three times the strength of talc at room temperature. Specimen B in Fig. 2, having a more intense pattern for protoenstatite, had a compressive strength of about 80 000 psi (5600 kg/cm²) at 1100°C, which is approximately equal to that of sintered alumina at this temperature.⁶ However, it should be noted that above 1100°C the strength decreases with increasing temperature even though the x-ray diffraction pattern of protoenstatite is still better defined. Neither specimens A, B, or C contained sufficient cristobalite to be detectable by x-ray diffraction, although a specimen fired at 1175° for 1 h contained a small amount.

The stress-strain curves in Fig. 1 indicate that the bulk modulus of elasticity increases with increasing temperature up to 1100°C. Specimen C at 1175° and specimen D at 1300° did not fracture but continuously deformed plastically under the compressive load. The scatter in the data in Fig. 2 at 1100°C is attributed to the lack of ductility in the samples.

The transformation of the talc at approximately 800°C to protoenstatite, silica, and water is also reflected by the weight loss and differential thermal analysis, and volume shrinkage curves as shown in Figs. 3 and 4, respectively. A comparison of the weight loss data with the strength measurements and the x-ray diffraction analyses indicates that it would not be possible to dehydrate talc without obtaining an appreciable increase in strength due to the formation of protoenstatite. The water expelled from the talc is a possible source of contamination if the samples in a high-pressure cell are not well sealed. This water may

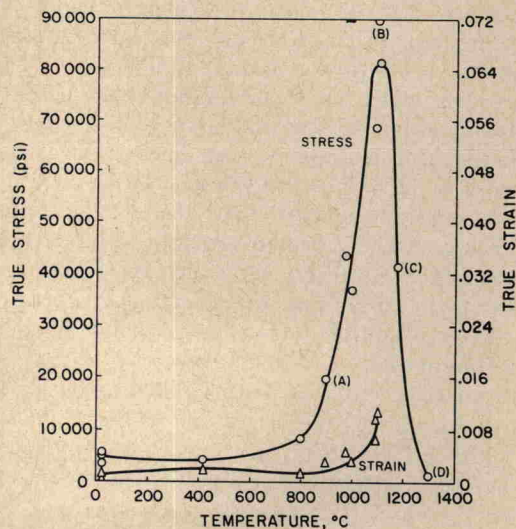


Fig. 2. Ultimate stress and strain for talc in compression at various temperatures.

⁴ A. Nadai, *Theory of Flow and Fracture of Solids* (McGraw-Hill Book Company, Inc., New York, 1950), p. 70.

⁵ R. B. Graf, F. M. Wahl, and R. E. Grim, *Am. Mineral.* 47, 1276 (1962).

⁶ E. Ryshkewitch, *Oxide Ceramics* (Academic Press Inc., New York and London, 1960), Chap. 2, p. 140.