

MEASUREMENT OF ELASTIC PROPERTIES OF UO_2 PELLETS BY ULTRASONICS

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SUMMARY: Uranium dioxide (UO_2) is the uranium compound that has been used for water cooled reactors since the early days of nuclear reactor technology. Although UO_2 pellets are fabricated today on a large scale, research and development studies are still going on. In this study, UO_2 powder which was produced at Nuclear Fuel Technology Department of ÇNRTC was pressed up to % 50 TD and sintered under %90 Ar and %10 H_2 atmosphere at 1400 °C, 1500 °C, 1600 °C, and 1700 °C for duration of 1, 2, 3, 4, and 5 hours. Pellet densities, longitudinal and shear wave ultrasonic velocities at each pellet were measured. After ceramographic preparation, average grain diameter for each pellet was found. Elastic properties of pellets were determined from these measurements. The change of the Young's modulus, shear modulus and bulk modulus with respect to density and mean grain diameter of pellets were studied.

INTRODUCTION

The structural properties of UO_2 ceramic pellets, used as fuel in water cooled nuclear power reactors, affect their physical behaviour during reactor operation. Density, porosity, grain size and elastic constants are very critical parameters to obtain a good performance from the pellets. Controlling of these parameters will help the optimization of fuel production conditions as well as the increasing of the reactor performance.

Ultrasonic velocity and the elastic constants are related to each other. The elastic constants of the UO_2 pellets were determined by measuring the speeds of the longitudinal and transverse waves (V_l and V_t respectively) and using the relations:

$$Y = V_t^2 (4 V_l^2 - 3 V_t^2) \rho / (V_l^2 - 3 V_t^2)$$

$$\mu = \rho V_t^2$$

$$B = \rho (V_l^2 - (4/3) V_t^2)$$

$$\sigma = (V_l^2 - 2 V_t^2) / 2 (V_l^2 - V_t^2)$$

Where Y is Young's modulus, it is defined as the tensile stress divided by the resulting elongation per unit length.

μ is the ratio of shearing stress to the shearing strain and called coefficient of rigidity or the modulus of shearing elasticity.

B is the ratio of the change in hydrostatic pressure to the change in volume per unit volume and called bulk modulus.

σ is called Poisson's ratio and it is the ratio of the compressive strain at right angles to the tensile stress, to the tensile strain along the stress axis.

For isotropic homogeneous medium, polycrystalline UO_2 can be put to this category, Young's modulus and Poisson's ratio can be expressed in terms of B and μ as:

$$Y = (3B\mu) / (B + (1/3)\mu)$$

$$= (B - (2/3)\mu) / (2B + (2/3)\mu)$$

EXPERIMENT

UO₂ powder produced through the ADU (ammonium diuranate) route was pressed under 300 MPa in steel dies to produce green pellets of 50% of TD (theoretical density of UO₂, 10960 kg/m³). These pellets were sintered under the atmosphere of 90% Ar + 10% H₂ at the temperatures of 1400 °C, 1500 °C, 1600 °C, and 1700 °C for duration of 1, 2, 3, 4, and 5 hours.

The densities of sintered pellets were measured by immersion method. After ceramographic preparation average grain diameter for each pellet was found by using semiautomatic image analyzer.

Longitudinal and shear wave velocities were measured by using pulse-echo overlapping and direct contact method with Kroutkraker USN52R model instrument and Kroutkraker MB4F probe.

RESULTS

The results of this study can be seen from the Figure 1 to Figure 12. At these figures, Figure 1 to 6 show the change of the longitudinal wave velocity, shear wave velocity, Poisson's ratio, Young's modulus, shear modulus, and bulk modulus with respect to the density of the pellets and the figure 7 to 12 show the change of the respective physical quantities with respect to the mean sphere diameters of the grains of the UO₂ pellets. The change of the above physical quantities with respect to density and mean grain diameter of the pellets can be summarized as:

$$V_L = (87,32\rho' - 3154)\text{m/s}$$

$$V_s = (57,6\rho' - 3705)\text{m/s}$$

$$\sigma = -0,0024\rho' + 0,67$$

$$Y = (5,78 \cdot 10^9 \rho'^4 - 4,56 \cdot 10^{11}) \text{N/m}^2$$

$$\mu = (2,05 \cdot 10^9 \rho'^4 - 1,62 \cdot 10^{11}) \text{N/m}^2$$

$$B = (8,05 \cdot 10^9 \rho'^5 - 5,36 \cdot 10^{11}) \text{N/m}^2$$

$$V_L = (33,14D + 4780) \text{m/s}$$

$$V_s = (18,94D + 1575) \text{m/s}$$

$$\sigma = -0,0006D + 0,439$$

$$Y = (2,13 \cdot 10^9 D + 7,14 \cdot 10^{10}) \text{N/m}^2$$

$$\mu = (7,55 \cdot 10^8 D + 2,48 \cdot 10^{10}) \text{N/m}^2$$

$$B = (3,34 \cdot 10^9 D + 1,95 \cdot 10^{11}) \text{N/m}^2$$

Where $\rho' = (\text{true density/theoretical density}) \cdot 100$, and D is the average grain diameter in micron.

When we compare Young's modulus value with literature * it is less than them .

*Stehle, H., H. Assmann, and F. Wunderlich, "Uranium Dioxide Properties for LWR Fuel Rods", Nuclear Engineering and Design 33 (1975) 230-260

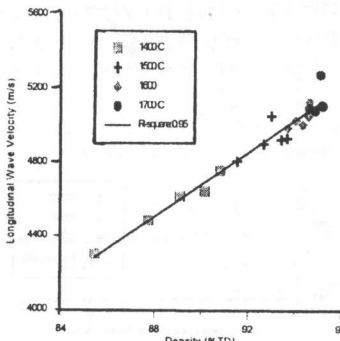


Figure 1: Longitudinal Wave Velocity Versus Density of UO_2 Pellets

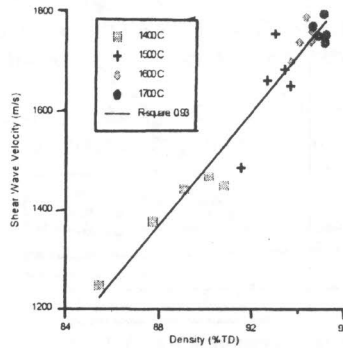


Figure 2: Shear Wave Velocity Versus Density of UO_2 Pellets

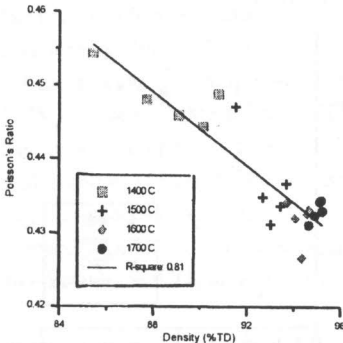


Figure 3: Poisson's Ratio Versus Density of UO_2 Pellets

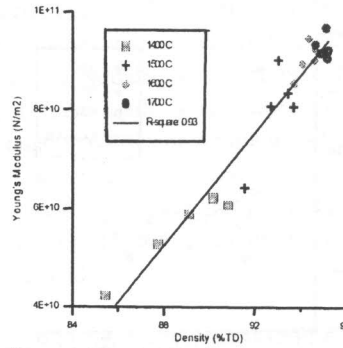


Figure 4: Young's Modulus Versus Density of UO_2 Pellets

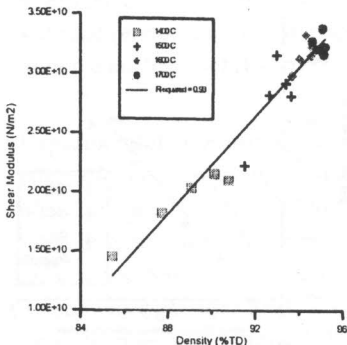


Figure 5: Shear Modulus Versus Density of UO_2 Pellets

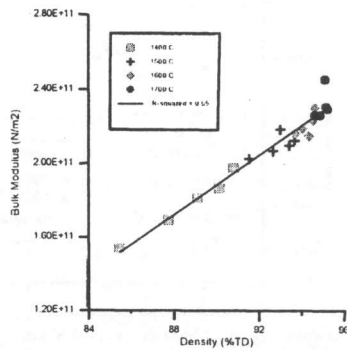


Figure 6: Bulk Modulus Versus Density of UO_2 Pellets

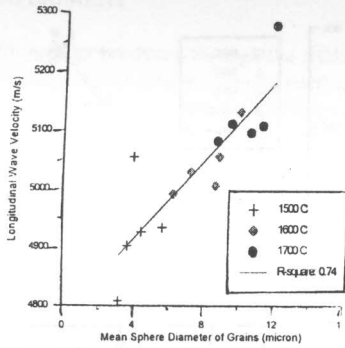


Figure 7: Longitudinal Wave Velocity Versus Mean Sphere Diameter of Grains of UO_2 Pellets

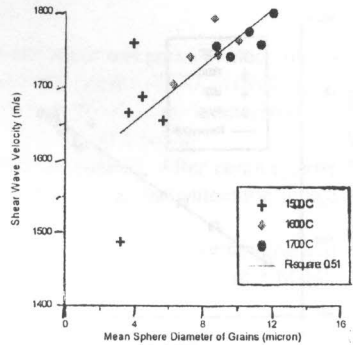


Figure 8: Shear Wave Velocity Versus Mean Sphere Diameter of Grains of UO_2 Pellets

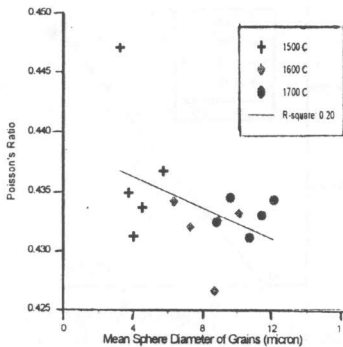


Figure 9: Poisson's Ratio Versus Mean Sphere Diameter of Grains of UO_2 Pellets

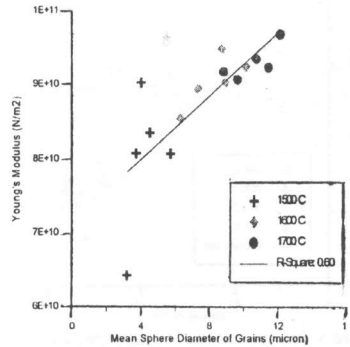


Figure 10: Young's Modulus Versus Mean Sphere Diameter of Grains of UO_2 Pellets

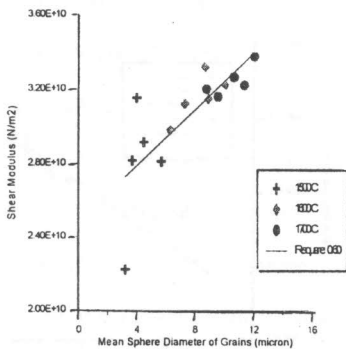


Figure 11: Shear Modulus Versus Mean Sphere Diameter of Grains of UO_2 Pellets

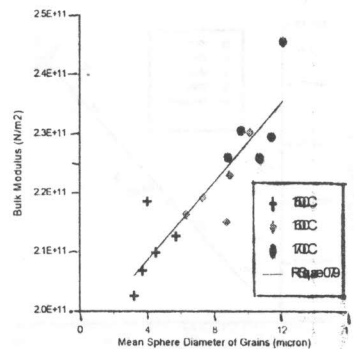


Figure 12: Bulk Modulus Versus Mean Sphere Diameter of Grains of UO_2 Pellets