

EXPERIMENT

THERMAL EXPANSION OF SOLID MATERIALS

AIM: To study the thermal expansion behaviour of solid materials using a dial gauge dilatometer.

THEORY:

Almost all materials expand on heating. This can be understood in terms of the potential energy curve. Consider a pair of atoms, bound together in the solid. The potential energy, $V(r)$, of these two atoms varies with their separation, r , and can be represented by

$$V(r) = -a/r^m + b/r^n$$

where a , b , m , and n are constants, and are positive quantities. The first term on the right arises from the attraction between the two atoms (decreasing r lowers the energy); the second term comes from repulsion. These two terms are shown as dotted lines in Fig. 11.1 and the total potential energy by a solid line. The asymmetric shape of the potential energy curve may be noticed. The degree of asymmetry is a function of the values of the exponent's m and n in equation. (11.1) m is always less than n . In ionic crystals, $m \sim 1$ and $n \sim 12$. In molecular crystals, $m \sim 6$. Note that $m = 1$ corresponds to coulomb attraction between two point charges. At temperature T_1 , corresponding to energy E_1 , the interatomic distance oscillates from r_1^I to r_1^{II} with a mean separation of $r_1 = (r_1^I + r_1^{II})/2$. At a temperature $T_2 > T_1$, the energy is E_2 and the average interatomic separation is r_2 oscillating between r_2^I and r_2^{II} . Note that $r_2 > r_1$ leading to thermal expansion. Thus, the asymmetric shape of the potential energy curve, which results in anharmonic nature of the lattice vibrations, is responsible for the thermal expansion) A large binding energy leads to a high melting point of a material, i.e., a deep potential energy minimum; in this case, at not too high temperatures, the potential energy curve would be asymmetric only to a small extent. Therefore, a material with

a high melting point (T_m , °K) would, near room temperature exhibit a low thermal expansion coefficient (α). The product (αT_m), is often empirically found to be constant for a series of related materials.

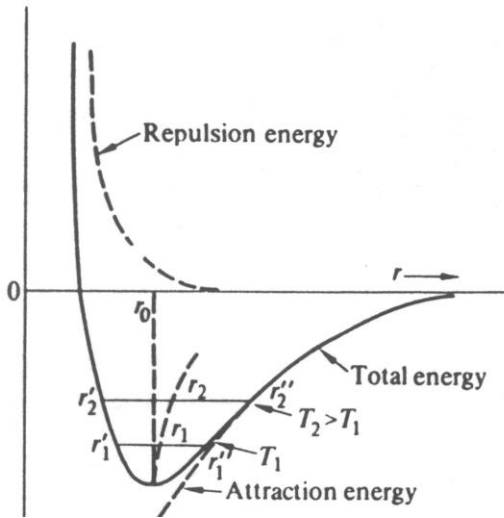


Fig II.1 Potential energy Vs interatomic distance

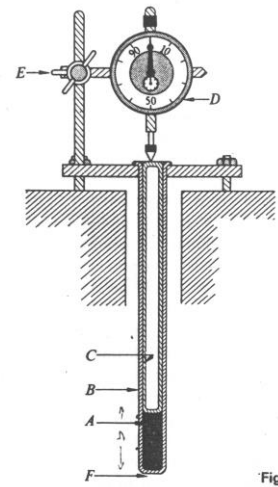


Fig. II.2 Dilatometer assembly

Isotropic materials can be described by a single potential energy curve and therefore exhibit the same thermal expansion in all directions i.e. have a single value of α . However, non isotropic crystals have potential energy Vs r curves of different shapes in different directions; consequently they possess different α values in various directions. A poly crystalline specimen of randomly oriented non isotropic crystals exhibits an expansion behavior which is an average of that in the various directions.

Similarly a multiphase material has thermal expansion behavior which is a weighted average of the expansion coefficients of its component phases. Differential dilatation in different directions in non isotropic materials or in different grains in a multiphase material, may lead to micro cracks and poor mechanical strength.

Determination of the thermal expansion coefficient requires the measurement of two physical quantities, displacement and temperature, for a sample of the material that is undergoing an appropriate thermal cycle. A diverse range of techniques can be employed for this purpose, and the main ones are outlined below.

i) Dial gauge (mechanical magnification) **(ii)** Optical lever (tilting mirror moves a light beam) **(iii)** Electrical transducer (capacitive or inductive) **(iv)** Resistance strain gauge **(v)** Optical interferometer. Of these the dilatometer with the dial gauge is the simplest and the most common method.

Mechanical Dilatometry is one of the most popular techniques for thermal expansion measurement. A specimen is heated in a furnace and the displacement of the ends mechanically transmitted to a displacement sensor by means of push rods. These can be made from low expansion fused silica for operation to 700°C. Alumina can extend the technique to 1600°C, and more extreme temperatures require the use of graphite. By compensating for the expansion of the push rods, accuracies of around 1-2 % for the CTE can be obtained.

EQUIPMENT:

A fused-silica tube, dial-gauge dilatometer, Furnace, Power supply, Temperature controller, Potentiometer, Thermocouple (chromel-alumel). Specimens (Pyrex. soda- lime-silica glass. aluminum. mild steel. building brick. fireclay brick. etc.

PROCEDURE:

1. Mount one of the samples (A) at the bottom of the fused-silica tube (B) which is closed at one end. A fused-silica tube (C), closed at both ends, is placed on top of the specimen. A dial gauge (D), with a least count of 0.001 mm, is attached to the top of the outer silica tube by an inconel clamp (E). The completed assembly is shown in Fig. 11.2

2 The whole assembly is inserted in a tube furnace, the temperature of which is controlled with a chromel-alumel thermocouple.

3. The apparatus is equilibrated at different temperatures. The dial gauge reading and the temperature of the specimen determined with a thermocouple (chromel-alumel) located at

F (Fig 11.2) and a potentiometer.

OBSERVATIONS:

1. Note the initial dimensions of the sample and the dial gauge reading.
2. Plot. $(\Delta L/ L_0)$ Vs Temperature.
3. Calculate the average linear thermal expansion coefficient from the plot.

$$\alpha = 1/L_0) .(\Delta L/ \Delta T)$$

QUESTIONS:

1. How do you correct the value of α ?
2. What is the volume expansion coefficient of your sample?
3. Why are fused silica and inconel used for dilatometer construction?
4. Why do we use a fused-silica tube closed at both ends instead of a fused silica rod?
5. Can you use the same dilatometer for measurements below room temperature?
6. What is the magnification of the dial gauge that you used? How can you increase it?