THE AMERICAN MINERALOGIST, VOL. 55, JULY–AUGUST, 1970

MINERALOGICAL NOTES

CLEAVAGE SURFACE ENERGY OF PHLOGOPITE MICA

PAUL L. GUTSHALL, PAUL J. BRYANT AND GEORGE M. COLE,
University of Missouri-Kansas City, Kansas City, Missouri 64110.

ABSTRACT

The cleavage surface energy of both natural and synthetic phlogopite mica has been measured. The cleavage energy mesaurements were performed in a high vacuum system to limit environmental effects. The cleavage surface energy of natural phlogopite measured in a vacuum of 10^{-7} Torr was 3630 ergs/cm^2. The cleavage surface energy of synthetic phlogopite measured in a similar vacuum was 6060 ergs/cm^2. The large difference between the cleavage surface energy of natural and synthetic phlogopite is apparently due to the impurities in the natural phlogopite.

INTRODUCTION

An understanding of the mechanisms of cohesion between surfaces has been the subject of many research programs. Engineering problems such as "cold-welding", stress corrosion and lubrication might be answered with a better insight into the mechanisms of cohesion. The purpose of this paper is to present data which will increase our knowledge of the phenomenon of cohesion.

The phyllosilicate family of minerals is ideal for studying cohesion between clean, atomically smooth surfaces. Phlogopite, a member of the phyllosilicate family, is a magnesium tetra silicate mineral. Phlogopite was chosen for this study because of its availability in both natural and synthetic forms.

The cleavage surface energy of natural and synthetic phlogopite was determined by measuring the amount of energy necessary to produce unit area of new surface. Earlier studies on muscovite (Bryant, Taylor and Gutshall, 1963) have shown the cleavage surface energy to be a function of the test environment. Therefore, the experiments reported here were performed in a vacuum of 10^{-7} Torr. The test system consisted of a glass chamber attached to a 15 liter/sec. getter ion vacuum pump (Fig. 1). A metal bellows and rod assembly, attached to the glass chamber through a kovar glass seal, was used to apply a force sufficient to produce cleavage within the specimen. For a complete description of the experimental methods of measuring the cleavage surface energy see Bryant, Taylor and Gutshall, 1963.

CLEAVAGE OF NATURAL PHLOGOPITE

Specimens of phlogopite (10 mm×50 mm×0.2 mm) were cut from large pieces of naturally occurring phlogopite. The natural phlogopite

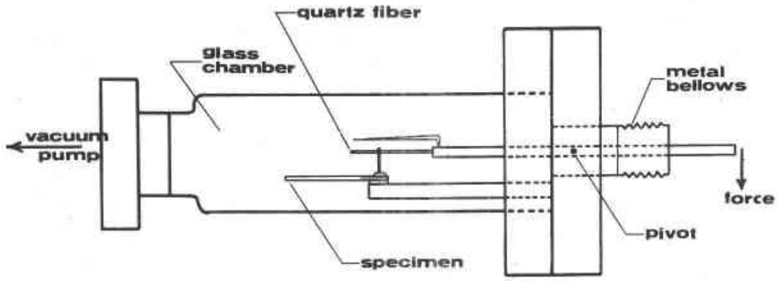

FIG. 1. Test Chamber for measuring the cleavage surface energy of phlogopite mica. A calibrated quartz fiber was used to measure the force necessary to produce cleavage.

has a reddish-brown color and contains large impuity centers (25-100 microns) dispersed throughout the material. Although an accurate determination of the impurities in the natural phlogopite was not made, it is believed that the major impurity consists of iron oxides. The cleavage surface energy of natural phlogopite was measured in a vacuum of 10^{-7} Torr and in 1 atm of laboratory air with a relative humidity of 30 percent. The results of these measurements are summarized in Table I. The cleavage surface energy of 3630 ergs per cm^2 as measured in vacuum, decreases to 700 ergs per cm^2 in air. The dependence of the cleavage surface energy on environment is similar to that observed for muscovite (Bryant, 1962). It was further determined that the interaction of air to cause a reduction in cleavage surface energy occurred for pressures above 1 Torr.

CLEAVAGE OF SYNTHETIC PHLOGOPITE

The cleavage surface energy of synthetic phlogopite was measured in vacuum and in air. The samples are transparent and contain very little impurity. Values of the cleavage surface energy of synthetic phlogopite

TABLE 1. CLEAVAGE SURFACE ENERGY OF PHLOGOPITE MICA

Type	Pressure	Cleavage Surface Energy[a] (ergs per cm^2)
Natural	10^{-7} Torr	3630
	1 atm.	700
Synthetic	10^{-7} Torr	6060
	1 atm.	500

[a] The values shown are averaged over at least 10 measurements. The coefficient of variation is less than 20% in all cases.

are presented in Table I. The pressure dependence of the cleavage surface energy was observed to be 500 ergs/cm^2 in air versus 6060 ergs per cm^2 in vacuum. The interaction of air to reduce the cleavage surface energy occurred for pressures above 1 Torr.

Discussion

The presence of impurities in the phlogopite samples studied here, reduces the cleavage surface energy. The high purity specimens of phlogpite yielded a cleavage surface energy of 6030 ergs per cm^2 while the value for natural phlogopite was 3630 ergs per cm^2. This trend is further substantiated when one considers that natural muscovite has a similarly low cleavage surface energy of 4750 ergs per cm^2 (Bryant, 1962). The muscovite used in those studies was a high grade electronic mucsovite, with more impurity than the synthetic phlogopite, but less than the natural phlogopite. The impurity present in phlogopite should be positioned between the lamellar layers. Since the interlayer binding forces in phlogopite are ionic, these forces are a function of the interlayer spacings. If the lamellar sheets in phlogopite are forced further apart by impurity atoms, then the binding forces are reduced. This results in a lower cleavage surface energy. Although the above explanation is oversimplified, it may account for the observed reduction in the surface cleavage energy of phlogopite.

The reduction of the cleavage surface energy with increasing impurity in phlogopite does not necessarily apply to nonlamellar materials. The cleavage surface energy of calcite increases by a factor of 3 with trace amounts of impurities [Gupta and Santhanam, 1969]. Similar results were observed for the alkali halides [Gilman, 1960]. Thus the effect of impurities upon lamellar structures may be (in some cases) different than for nonlamellar materials.

Acknowledgment

This work was supported by the National Aeronautics and Space Administration-Langley Research Center on NASA Grant No. NGR 26-001-006.

References

Bryant, P. J. (1962) Cohesion of clean surfaces and the effect of adsorbed gas. *In* G. H. Bancroft (ed.) *Trans. Ninth Nat. Vacuum Symp.*, Macmillian and Co., New York, 311–313.

———, L. H. Taylor and P. L. Gutshall (1963) Cleavage studies of lamellar solids in various gas environments, *in* G. H. Bancroft, (Ed.) *Trans. Tenth Nat. Vacuum Symp.*, Macmillian and Co., New York, 21–26.

Gilman, J. J. (1960) Direct measurements of the surface energies of crystals, *J. Appl. Phys.* **31**, 2208–2218.

Gupa, Y. P. and A. T. Santhanam (1969) On cleavage surface energy of calcite crystals, *Acta Met.* **17**, 419–424.