

THE FORMATION OF LUNAR GLASSES, L. Klein, G. Kritchevsky, R. W. Hopper and D. R. Uhlmann, Dept. of Metallurgy and Materials Science, Center for Materials Science and Engineering, M.I.T., Cambridge, Mass. 02139

In a continuing investigation of the conditions for forming glasses in the lunar environment and the information provided by such glasses and partially devitrified bodies about thermal history, attention has been directed to two compositions (60095 and 65016) which were found as largely-glassy bodies of relatively large mass (46.6 and 21.0 g. respectively) as well as to the Apollo 15 green glass. Experimental determinations of the viscosity and crystal growth rate have been effected over a wide range of temperature for the 60095 and 65016 compositions, and are presently underway on the Apollo 15 green glass material. These data are then combined with theoretical kinetic analyses (1, 2, e.g.) to obtain the desired information about glass formation and thermal history.

The viscosity data were in all cases obtained on synthetic materials prepared from reagent grade raw material powders. The techniques of sample preparation have been described in detail elsewhere (3), and involve melting under conditions of low oxygen activity to simulate the $\text{Fe}^{2+}/\text{total Fe}$ ratios of the lunar compositions. Viscosities in the molten range were obtained using a rotating-cylinder viscosimeter. The instrument employed here differs from that described previously (3) in its use of a Haake-Brabender Rotovisco instrument with its E suspension system to effect the torque determination. Viscosities greater than about 10^8 poise were determined using a bending-beam viscosimeter which has been described in detail elsewhere (3). Both viscosimeters were provided with a low- H_2 forming gas atmosphere to maintain the $\text{Fe}^{2+}/\text{total Fe}$ ratios of the starting materials.

The viscosity data obtained on the 60095 and 65016 compositions are shown in Fig. 1. In both cases, crystallization prevented the obtaining of reliable data at intermediate temperatures. Also shown for comparison in Fig. 1 are the results reported previously (4) for the 68502 composition. Over the full range of temperature, the viscosities fall in the order: $\eta(68502) > \eta(65016) > \eta(60095)$; and over the full range of temperature the viscosities of all the Apollo 16 compositions are higher than those of the 15555 and 74220 materials.

The apparent activation energies for viscous flow in the high-temperature and low-temperature regions are about 60 kcal mole⁻¹ and 145 kcal mole⁻¹ for the 65016 composition and about 55 kcal mole⁻¹ and 155 kcal mole⁻¹ for the 60095 composition. These values lie in the range of those found previously for other lunar compositions (3, 4, e.g.).

The measurements of crystal growth rates were carried out using techniques described in detail elsewhere (5). Under all conditions where it could be determined, the interface morphology was observed to be faceted. In all cases, the crystals propagated from the external surfaces into the interiors of the specimens. The thickness of the external crystal layer after a given time of heat treatment at a given temperature was found to be uniform within about 5 pct.; and the thickness was observed to increase

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linearly with time.

The growth rates, determined from the slopes of the thickness vs. time relations, varied with temperature as shown in Fig. 2 for the 60095 composition. Similar variations of growth rate with temperature are found quite generally for glass-forming materials. The maximum in the growth rate curve reflects a competition between the driving force for crystallization and the molecular mobility.

The variations of growth rate with undercooling below the liquidus have been combined with the corresponding variations of viscosity to construct the reduced growth rate U_R vs. undercooling relations. Here $U_R = u\eta/\Delta T$, where u is the growth rate, η is the viscosity and ΔT is the undercooling. The variation of U_R with ΔT directly indicates the temperature dependence of the interface site factor, and hence serves to characterize the nature of the interface kinetic process. For the present compositions, as for all lunar compositions previously investigated, the U_R vs ΔT relations exhibit positive curvature and are suggestive of growth by a surface nucleation mechanism.

To investigate further this possibility, $\log(u\eta)$ vs $1/T\Delta T$ relations have been constructed. Similar to the results obtained on other lunar compositions, these relations for the present compositions exhibit negative slopes and positive curvatures. The forms of these relations are inconsistent with the standard models for surface nucleation growth, but are in accord with recent computer simulations of crystal growth (6, e.g.).

The experimental results on growth rate and viscosity have been combined with kinetic treatments of glass formation (1, 2) to evaluate the glass-forming characteristics of the present compositions. The estimated critical cooling rates for glass formation are consistent with experimental observations on both synthetic and natural lunar compositions. The inversion of the experimental observations of crystal distributions in the natural samples to determine their thermal histories (2) are presently underway, and it is hoped that the results can be given in the verbal presentation.

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Fig. 2

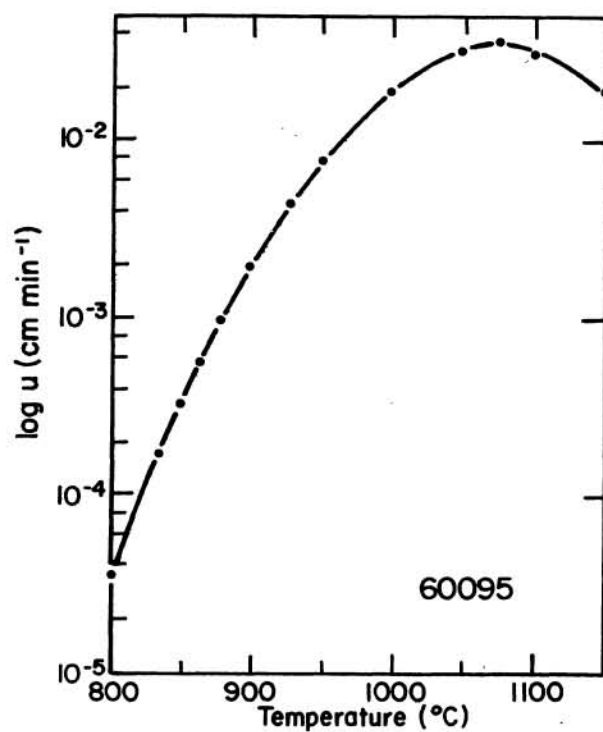


Fig. 1

