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Effect of the roughness of crucible on viscosity of liquid $Pb_{38.1}Sn_{61.9}$ alloy

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Abstract

The viscosity of the eutectic $Pb_{38.1}Sn_{61.9}$ alloy has been measured by a torsional oscillation viscometer using three different crucibles which are made of the materials of highly sintered alumina (Al_2O_3), quartz (SiO_2), and graphite (C) respectively. The roughness of crucibles has effect on the viscosity. The viscosity data obtained for SiO_2 and C crucibles were concentrated in the narrow range of about 0.5% and showed almost the same activation energy. However, the viscosity obtained using Al_2O_3 crucible with the maximal roughness is higher than that using the other two crucibles. The discrepancy of viscosity obtained using those crucibles increases with the viscosity. In addition, the viscosity obtained using three kinds of crucibles in our work has a breakpoint at 488 K, which is approximate with the results of electrical conductivity and thermopower measurements reported by Plevachuk et al., which indicates the microstructure in melt changes before solidification.

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Keywords: Viscosity; Activation energy; Roughness; Discrepancy; Melting point

1. Introduction

Viscosity as an important physical property is sensitive to the melt structure and friction among atoms [1]. Investigations on the viscosity of metallic melts remain one of the active domains of research in both the technical and theoretical fields of condensed matter physics [2,3]. Although viscosity values of liquid metals are important in the prediction of fluid flow in many metallurgical manufacturing processes, there are few data available for pure metals, and even less for alloys, and literature values can show a high degree of scatter, due to the low viscosities, the chemical reactivity, and the generally high melting points of the liquid metals. Various studies [1,4] have suggested that wetting of crucible may also be important, and that if the metal does not wet the crucible it may be slip during the oscillation and thus provide low viscosity. However, some investigators do not agree with the standpoint and suggest the slipping behavior do not exist during the crucible oscillating [5]. More studies are needed for observing the effect of crucible on the viscosity and obtaining the credible viscosity data.

Among different eutectics, Pb–Sn alloys have considerable potential for advanced structural and electronic applications. The intensive interest in these solder alloys is attributed to their low cost and unique material properties. Presently, the understanding of the microstructure of these alloys is still the subject of recent works [6,7]. A number of studies on the eutectic and near-eutectic alloys revealed that the behavior and properties of these systems were ambiguous and contradictory [8–11]. In this work, we measure the viscosity of the eutectic $Pb_{38.1}Sn_{61.9}$ alloy by using three kinds of crucibles to observe the effect of the crucible on the viscosity.

2. Experimental procedure

Viscosity measurements were performed using a torsional oscillation viscometer for high-temperature melts in the present work, as shown in Fig. 1. After the chamber was cleaned to a vacuum of 2×10^{-6} Pa, it was filled with high purity argon (99.999%) to 1.1×10^5 Pa. The samples used in this work were prepared from pure ingots Pb (99.95 wt.% pure) and Sn

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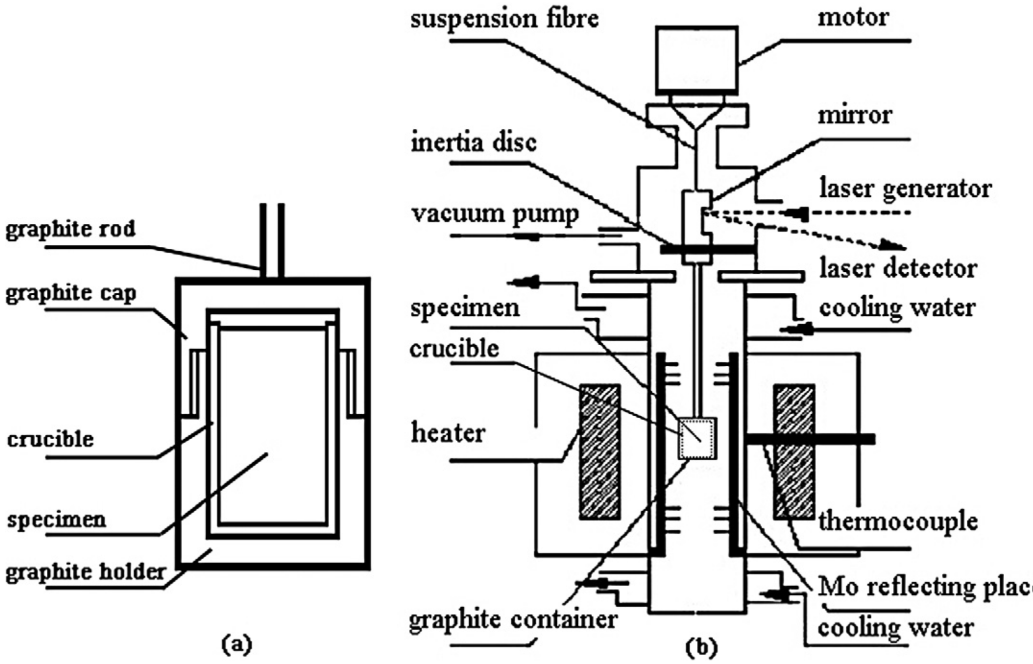

Fig. 1. (a) Sample holder, (b) schematic diagram of the oscillating viscometer.

Table 1
The parameters of different crucibles. D (inner diameter of crucible), H (height of crucible), M_1 (the mass of crucible), M_2 (the mass of specimen), R_a (the parameter of roughness)

Crucible	D (mm)	H (cm)	M_1 (g)	M_2 (g)	R_a (μm)
C	28	5.87	54.23	225.0	0.025
Al_2O_3	29	6.11	37.4	249.9	0.06
SiO_2	23.8	5.31	27.58	162.0	0.012

(99.98 wt.% pure). The samples were placed in a crucible hung by a torsional suspension, and heated at a rate of 4 K/min to 400 K above the melting point. After maintaining the temperature for three hours, samples were cooled down to the experimental temperatures and held there for one hour for equilibrium prior to taking measurements for each. Three kinds of crucibles, which were made of the materials of Al_2O_3, SiO_2, and C respectively, were used in experiments. The parameters of these crucibles were shown in Table 1. The parameters except the roughness were considered as variables and inputted the calculating formula. During the experiment, the SiO_2 crucible was set in the Al_2O_3 crucible, because the outer diameter of the SiO_2 crucible was too small to be riveted by the graphic container, as shown in Fig. 2. The SiO_2 crucible fitted the Al_2O_3 crucible well and does not slip against Al_2O_3 crucible during the measurement.

When a liquid was placed in a vessel hung by a torsional suspension, and the vessel was set in oscillation about a vertical axis, the resulting motion was gradually damped on account of the frictional energy absorption and dissipation within the liquid. The viscosity of the liquid sample can be calculated by observing the decrement and the time period of the oscillations. In this work, the kinetic viscosity data were calculated from the logarithmic decrement by Shvidkovskii's formula [12]. This

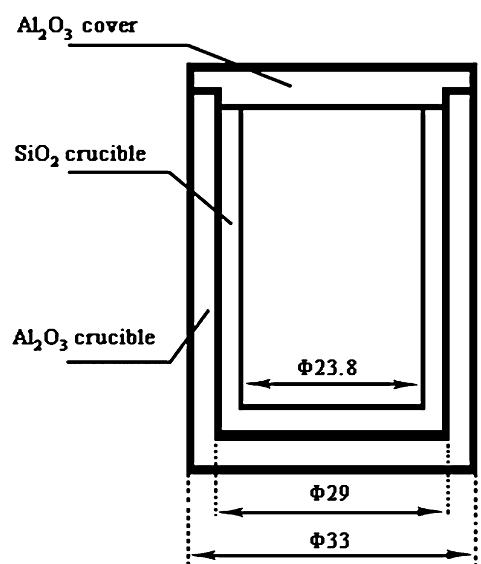

Fig. 2. Schematic diagram of the crucible.

formula is applicable when the parameter $\alpha = r(2\pi/\nu T)^{1/2}$ is greater than 10, and H is greater than or equal to $1.85r$:

$$\nu = \frac{I^2(\delta - T\delta_0/T_0)^2}{\pi(Mr)^2TW^2}, \tag{1}$$

where

$$W = 1 - \frac{3}{2}\Delta - \frac{3}{8}\Delta^2 - a + (b - c\Delta)\frac{2nr}{H} \tag{2}$$

$\Delta = \delta/2\pi$; I is the momentum of inertia of the suspended system; δ is the logarithmic damping decrement, and T is the period time of the oscillations, the subscript 0 refers to an empty vessel; M represents the mass of the liquid sample; r is the inner radius of the vessel; H is the height of the liquid sample in