Communications

Measurements of the Electrical Conductivity of Wood's Alloy and Other Low Melting Point Alloys

AMRITA VERMA and J.W. EVANS

In several recent investigations (*e.g.*, References 1 through 5), "Wood's alloy" has been used in physical models of metals processing units such as Hall–Héroult cells and electromagnetic casters. This alloy has some advantages, when compared to the obvious alternative, mercury; the most significant advantage is the avoidance of the toxic vapor problem of mercury. However, one disadvantage suffered by Wood's alloy is that its physical properties are less well known than those of mercury. Of particular interest to the authors is the electrical conductivity of Wood's alloy because of the alloy's use in physical modeling of electromagnetic phenomena in metals processing in their laboratories.

While handbooks and texts (*e.g.*, References 6 and 7) give values for the conductivity of liquid Wood's alloy, the present authors have been unable to find the source of these values and thereby to determine the temperature, composition, and reliability of these measurements. The only readily available prior publication is the 1916 thesis of Cooke,[8] which describes measurements of both thermal and electrical conductivities, although the description of the latter is brief. The authors were impelled to measure the electrical conductivity of Wood's alloy and took the opportunity to perform measurements on two additional low melting point alloys.

The apparatus used in the present investigation is shown in Figure 1. The V-shaped channel contained the alloy. It was drilled in a 27.8-mm-thick block of high-temperature polycarbonate. Nickel wires were inserted through the plastic into the channel so as to make electrical contact with the alloy. The heavier gauge wires were used to pass current (typically 0.45 Amps) from a DC power supply (HEWLETT-PACKARD* model 621B) through the alloy; the same current passed through a known resistor (0.418 mΩ). The lighter gauge wires were connected to a precision multimeter (SOLARTRON** 7071 computing voltmeter) enabling measurement of the potential drop between the two connecting points in the alloy. The same multimeter was used to measure the potential drop across the known resistor. The central well of the plastic block contained a precision mercury-in-glass thermometer, and the block was immersed in Syltherm 800 (to within approximately 7 mm of its top) in a covered constant temperature bath.

Wood's alloy (50 wt pct Bi, 25 pct Pb, 12.5 pct Sn, 12.5 pct Cd, mp 343 K) was prepared by melting weighed samples of reagent-grade constituents under argon and quickly pouring the alloy into the plastic block. Other compositions used were 50 wt pct Bi, 26.7 pct Pb, 13.3 pct Sn, 10 pct Cd (which is the composition of the alloy "Cerrobend," mp 343 K, available from Cerro Metal Products Company, Paramount, CA) and 50 wt pct Bi, 25 pct Sn, 25 pct Cd (mp 368 K, known as "fusible alloy"). These other compositions were prepared in the same way.

Preliminary experiments indicated that the temperature reached steady state after approximately 120 minutes, at which point the current was turned on and voltage measurements were commenced immediately. It was found that the resistance of the alloy increased slowly with time, at a rate that increased with current, presumably because of an electrical heating of the alloy. This increase was negligible over the time period of the measurements at 0.45 Amps, a current sufficient to give voltage measurements across the alloy and known resistor with required precision. After completing a set of measurements at each temperature, a caliper gage was used to measure the thermal expansion of the plastic to enable a correction for slight change in geometry due to this effect. The resistance of the alloy (between the potential measuring points) is obtained from

$$\text{measured alloy resistance} = \text{known resistor} \times \frac{\text{potential drop across alloy}}{\text{potential drop across resistor}} \qquad [1]$$

and Figure 2 depicts typical results for Wood's alloy indicating the reproducibility of the results between two separate runs.

Finally, a calibration of the apparatus was carried out at room temperature using mercury (99.9998 pct pure). The resistance of the mercury column measured in this way was 0.002142 Ω, which compares favorably with a value (0.002104 Ω) obtained by approximating the V-shaped column as a cylinder of the same diameter. The former number was used in the equation for calculating conductivity:

$$\text{alloy conductivity} = \frac{\text{mercury conductivity} \times \text{mercury resistance}}{\text{measured alloy resistance}} \times \left[\frac{\text{block thickness at room temperature}}{\text{block thickness at temperature}}\right] \qquad [2]$$

The factor in brackets allowed for increases in both column diameter and length due to thermal expansion (assumed isotropic) and was never less than 0.9963. The conductivity of mercury (1.0471×10^6 S/m) at 294.11 K, appearing in Reference 9, was used in Eq. [2].

The electrical conductivities of the three compositions appear in Figure 3 and Table I, together with the values

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*HEWLETT-PACKARD is a trademark of Hewlett-Packard Company, Colorado Springs, CO.

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Manuscript submitted November 1, 1993.

Table I. Conductivities for Various Alloys

Temperature (Deg K)	Conductivity (Mega S/m)		Temperature (Deg K)	Conductivity (Mega S/m)
	(Wood's Alloy in This Investigation)			(Wood's Alloy in Cooke's Thesis)
341.77	2.02	±0.08	337	1.45
348.55	1.46	±0.07	339	1.43
358.1	1.2	±0.05	349	1.01
367.66	1.15	±0.05	354	0.98
377.97	1.14	±0.05		
386.33	1.14	±0.05		
	(Wood's Alloy in Hughes & Young's book)			(Wood's Alloy in Metals Handbook)
358.6	0.93	—	—	4.17 pct of Cu (≈2.48)
373	0.9			
	(Cerrobend Alloy in This Investigation)			
339.63	2.12	±0.09		
348.96	1.39	±0.06		
358.11	1.19	±0.05		
367.06	1.14	±0.05		
375.35	1.13	±0.05		
384.61	1.11	±0.05		
	(Fusible Alloy in This Investigation)			
367.44	2.84	±0.11		
376.89	2.68	±0.1		
386.67	1.49	±0.06		
395.5	1.39	±0.06		
403.89	1.34	±0.04		

of Cooke* (52.34 wt pct Bi, 25.85 pct Pb, 14.73 pct Sn, 6.99 pct Cd) and (in Table I) other values for liquid conductivity at unknown temperatures. It is seen that the difference in composition between Wood's alloy and Cerrobend results in only a small difference in electrical conductivity and that Cooke's measurements on a similar alloy (the term Wood's alloy has been used for many similar compositions) yield similar values. However, reducing the lead content of these alloys from 25 to 26 pct to zero is seen to lead to a substantially higher conductivity for the fusible alloy.

Electrical conductivities of three low melting point alloys have been completed in order to yield a property of interest in the physical modeling of metals processing operations.

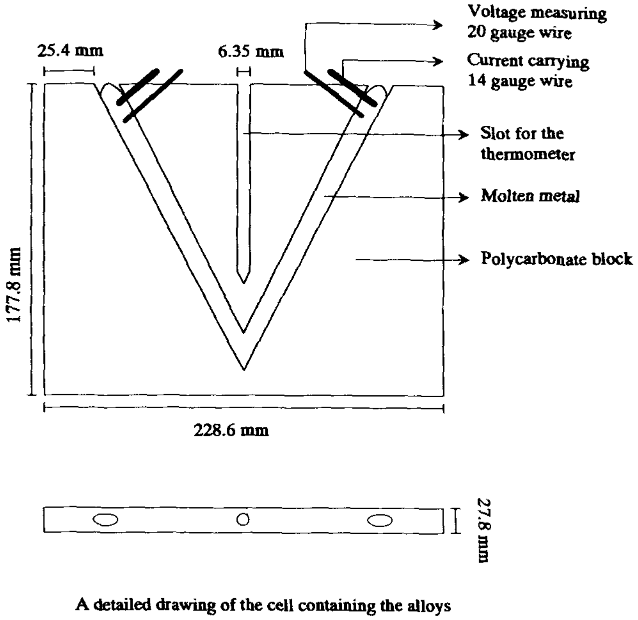

Fig. 1—Sketch of conductivity cell used.

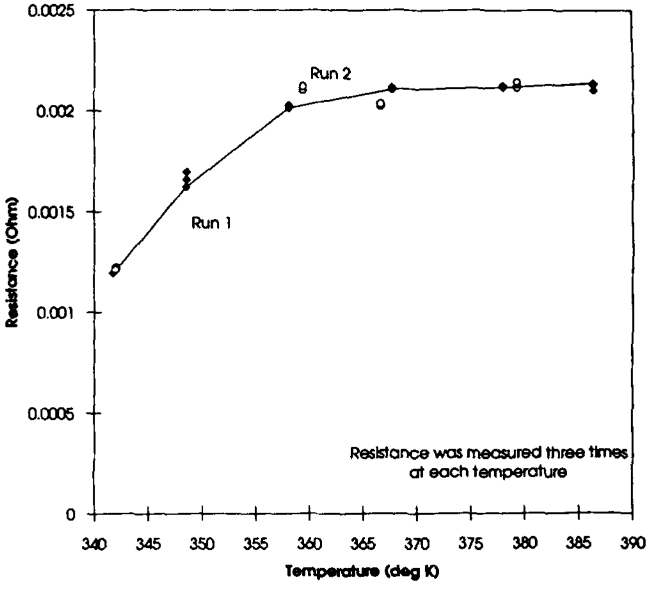

Fig. 2—Reproducibility of Wood's alloy resistance.

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*In fact, the values appearing in the figure are not ones tabulated in her thesis, which are given in unknown units. They have been calculated here from her potential measurements, known resistor values, and Wood's metal dimensions.

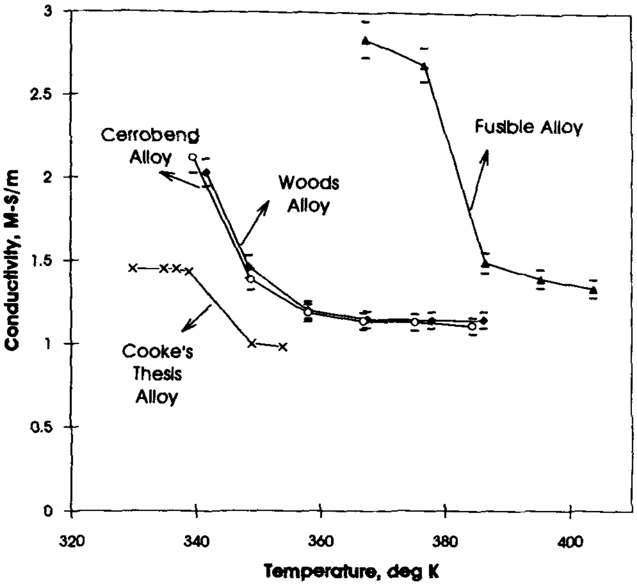

Fig. 3—Conductivity of various alloys *vs* temperature.

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Densities of Liquid Fe-Ni and Fe-Cr Alloys

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In order to study the gravity-driven flow of liquid metals and interfacial phenomena such as slag entrainment and metal emulsification, the densities of liquid metal alloys need to be accurately known. In the present study, the densities of liquid Fe-Ni and Fe-Cr alloys were measured at 1550 °C using the sessile drop technique. The densities that were determined were then compared with the values currently available in the literature.

A SiC resistance furnace was used to perform the sessile drop experiments for density measurements. An X-ray radiographic unit was employed to image the profile of the metal droplet, contained in a conical alumina crucible, at 1550 °C. The density of the liquid alloy was subsequently determined from the contour of the droplet by numerically solving the Young–Laplace equation. Details of the experimental setup, the data acquisition, and the computational technique are available in References 1 through 5.

The Fe-Ni and Fe-Cr alloys were prepared by melting measured quantities of solid pieces of the component metals in alumina crucibles using an induction furnace. The metal samples used for alloy preparation were of ultrahigh purity; the metallic purity of iron (from Noah Technology, San Antonio, TX) and chromium (from Johnson-Matthey, Ward Hill, MA) was 99.99 pct, whereas that of nickel (from Johnson-Matthey, Ward Hill, MA) was 99.995 pct. Conical pieces of the alloy, each weighing about a gram, were prepared for the sessile drop experiments. Each conical piece was then polished and washed with acetone to clean the surface of the alloy sample. The sample was carefully weighed with an accuracy of 0.0001 g before it was charged into the furnace. All experiments were carried out in extremely reducing atmospheres of CO_2-CO or Ar-H_2 gas mixtures. At least five experiments were performed for each alloy composition to minimize error, and an average density value was calculated.

The density of pure liquid iron at 1550 °C has been measured by a number of investigators in the past.[2,6–21] The available literature data have been summarized and compared with the result from the present work in Table I. The value of density determined for pure liquid iron in the present work (7.05 g/cm^3) is in reasonable agreement with a majority of the previous data and is in excellent agreement with the values determined by Frohberg and Weber[9] and Saito *et al.*[13]

There are fewer studies on the density of liquid nickel at 1550 °C than of liquid iron. Table II summarizes the data available in the literature on the density of liquid nickel at 1540 °C and 1550 °C.[12,17,22–25] The value measured in the present work at 1550 °C (7.68 g/cm^3), which is also listed in Table II for comparison, is in perfect agreement with that of Benedicks *et al.*[23] The density measurement due to El-Chansan *et al.*[25] carried out at 1540 °C, is also in excellent agreement with the present data.

The densities of liquid Fe-Ni alloys measured in the present work are plotted in Figure 1. Also plotted in the figure are the densities measured by previous investigators at 1540 °C and 1550 °C.[12,22–25] A reasonable agreement was found between the values determined earlier and the ones determined in the present work. Nickel additions to liquid iron increase the density of the Fe-Ni alloy, as nickel is a heavier metal than iron.

The densities determined by Benedicks *et al.*[23] show

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Manuscript submitted March 14, 1994.