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Research and Development Report

THE ELECTRICAL RESISTIVITY OF MOLTEN AND SOLID THORIUM-MAGNESIUM EUTECTIC

by

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ABSTRACT

The electrical resistivity properties of polycrystalline 39 w/o thorium-magnesium eutectic are reported for the solid from room temperature to its melting point of 589°C and as a liquid from its melting point to 900°C. The electrical resistivity of this eutectic at the melting point was 69.5 microhm-centimeters; it decreased to a value of 64.8 microhm-centimeters at 900°C.

Tantalum tubing was used to contain the alloy in the molten state.

INTRODUCTION

Considerable interest has been shown in atomic breeder reactors which produce more usable nuclear fuel than is expended. Eight or more reactors of this type have been completed or are under construction in the United States, Great Britain and the USSR. These reactors utilize thorium as a solid metal or as compounds in an aqueous slurry.

Advances have been recently completed in the pyrometallurgical separations and studies on molten metal components.[1] One of the low melting alloy eutectics, thorium-magnesium, was found to have suitable properties for the circulation of the blanket material.

It is important to know the electrical resistivity of the metal alloys used in these systems in order to (1) calculate the flow through electromagnetic pumps and (2) determine the characteristics of a heating transformer which is a loop containing molten alloys.

For the above reasons, this work was undertaken to obtain the electrical resistivity for thorium-magnesium eutectic which will be circulated as a molten liquid in a closed system.

SAMPLE PREPARATION

The literature values for the alloy composition of thorium-magnesium eutectic vary from ~ 35 w/o thorium as reported by Jones and Nash,[2] to 42 w/o by Yamamoto and Rostoker,[3] and 38-39 w/o by Peterson.[4] The melting points reported by these groups are 596, 582 and 588°C, respectively.

The thorium metal used for the alloy in the present work was prepared at the Ames Laboratory and the magnesium was obtained from the New England Lime Company and double distilled at Ames. The analyses for these materials are listed in Table I. Turnings from these metals were blended, compressed into briquettes and heated in a tantalum crucible by the use of an induction coil. The metals were heated to 500°C under vacuum at which time argon was admitted and the heating continued to 700°C. The furnace was maintained at this temperature for 4 hr and allowed to cool.

A micrograph of this material is shown in Fig. 1.

Table I

Analysis of Metals used in Preparing the Eutectic

Impurities	Thorium	Magnesium
Nitrogen	84 ppm	50 ppm
Carbon	250	200
Beryllium	110	N. D.
Iron	80	10
Calcium	N. D.	Trace
Oxygen	750	100
Nickel	N. D.	N. D.
Zinc	N. D.	N. D.
Aluminum	N. D.	N. D.
Manganese	N. D.	N. D.

N. D. (Not Detected)

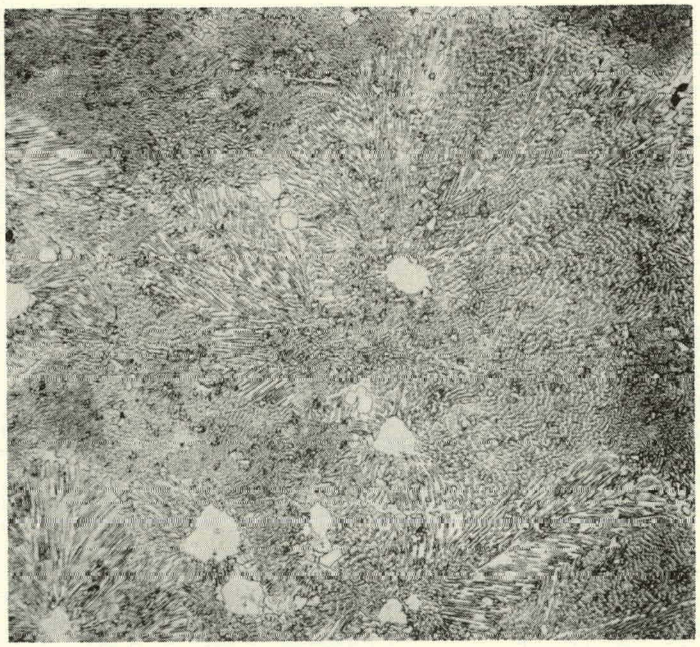

Fig. 1 - 39 w/o Thorium-Magnesium Eutectic, 250X.

EQUIPMENT AND EXPERIMENTAL PROCEDURES

All of the electrical measurements at high temperatures were conducted in the vacuum system described by Fullhart and Fisher.[5] The electrical circuit used is shown in Fig. 2. This circuit provides a means of current reversal between potential measurements and minimizes one of the chief sources of error caused by Seebeck effects as stated by Lark-Horovitz and Johnson.[6]

A temperature difference of 3°C at 925°C was observed across the sample from the center to the ends. Two platinum/13% rhodium thermocouples were used to obtain the proper average for the temperature of the sample. The resistivity system was standardized using platinum wire and the temperature was maintained by an automatic Beck program controller which maintained a temperature ±0.25% of full scale.

A Ribicon potentiometer capable of being read to one microvolt was used for potential measurements. A current of 0.075 amp or less was utilized to keep the heating effect of the current at a negligible level.

THORIUM-MAGNESIUM SOLID

The alloy of 39 w/o thorium-magnesium was milled to a rectangular bar having a cross section of approximately 0.070 in. The final dimensions were obtained at room temperature by means of a traveling microscope and a comparison micrometer capable of accuracy to ±0.00005 in.

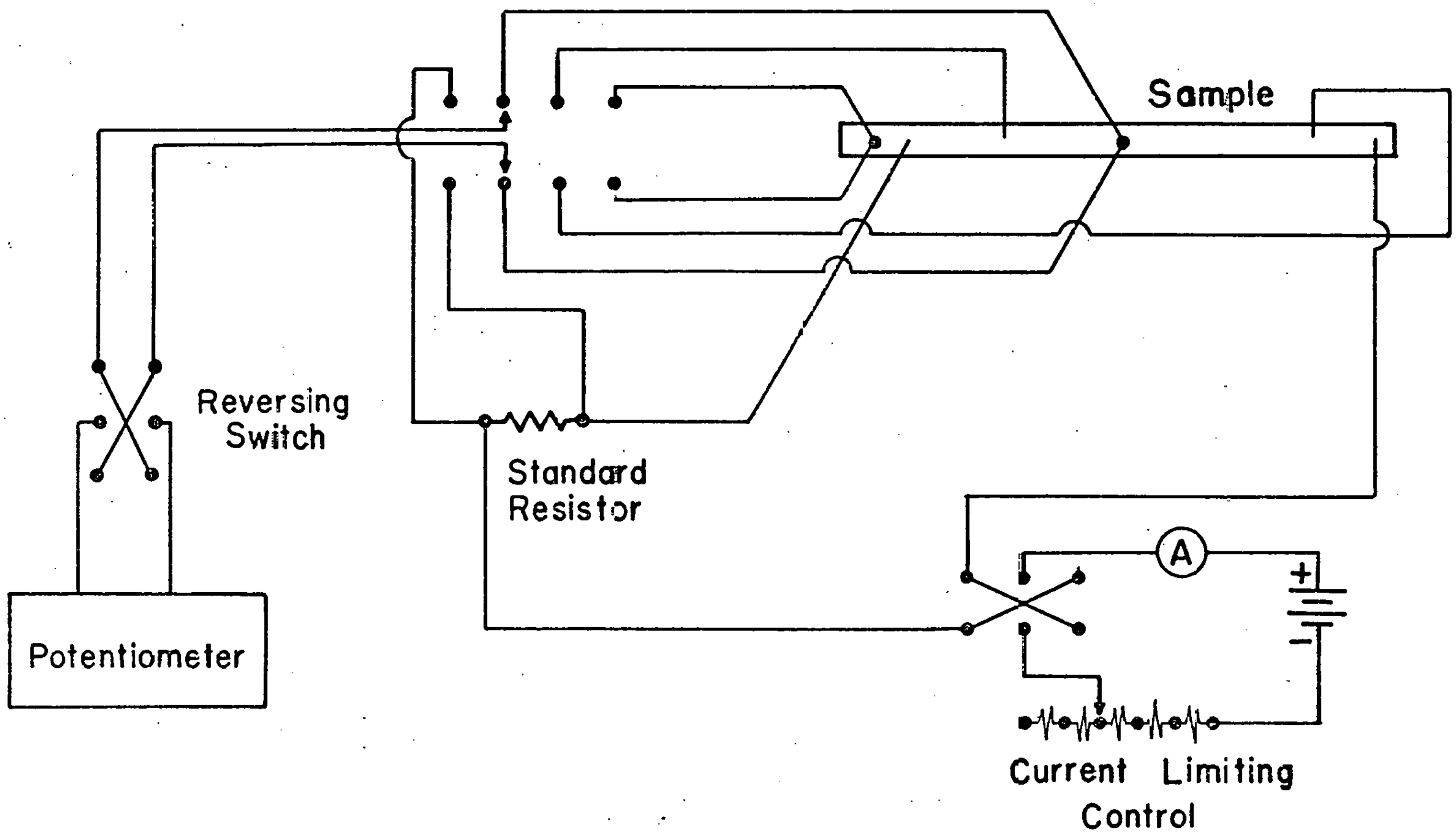

Fig. 2 - Potentiometric Circuit for Measuring Resistance.

Tantalum wire (20 mil) was used for current and potential leads which were spot welded to the sample in a helium atmosphere. The distance between leads was determined from the wire centers as described by Lark-Horovitz and Johnson.[6]

The electrical resistivity of these bars is shown in Fig. 3. The data were obtained for the alloy contained in tantalum. It should be noted that magnesium was volatilized from the solid bars beginning at 400°C.

THORIUM-MAGNESIUM LIQUID

Magnesium and thorium react readily with most container materials and gases, at and above the melting point of the eutectic. The vapor pressure of magnesium is one mm at 621°C.[7] Because of these factors and the corrosion resistance as determined previously,[1] tantalum was chosen for the container material.

Tantalum tubing of special purity was ordered from Kawecki Chemical Company for this work. The analysis of this material is shown in Table II. The electrical resistivity of the tubing without the alloy sample was determined for the temperatures and vacuum conditions used. It was found that even in a vacuum of 10^{-5} mm mercury at temperatures of 800-1000°C tantalum absorbs oxygen and consequently the electrical resistivity of the tubing changes. Variations from 14 to 17.4 microhom-centimeters have been observed in tantalum when measured at room temperature. The change in impurities from the original material to the oxidized material after four cycles of heating to 900°C in a vacuum of 1×10^{-5} mm mercury is shown in Table II. This

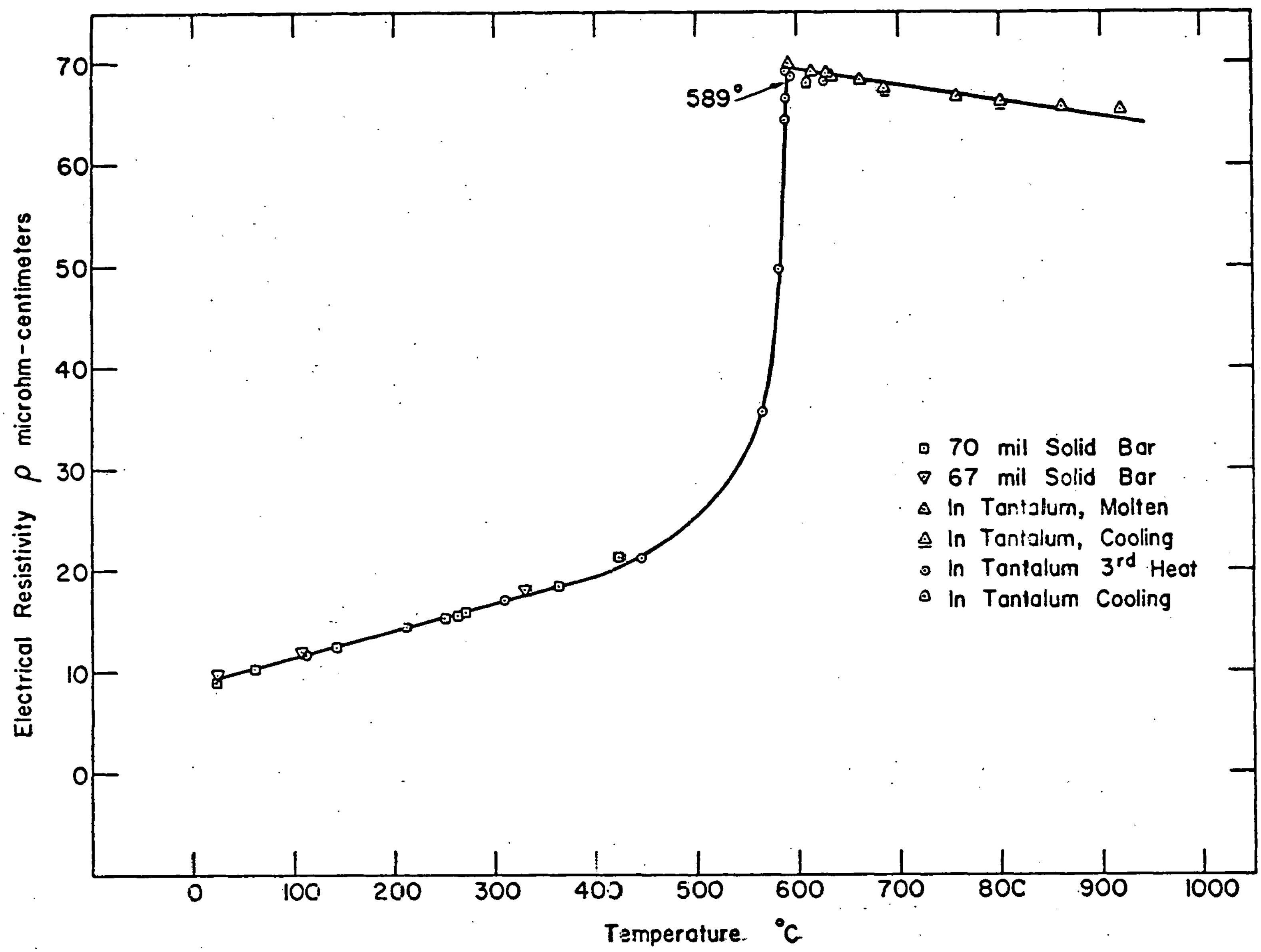

Fig. 3 - Electrical Resistivity of 39 w/o Thorium-Magnesium Eutectic.

Table II

Impurities in Tantalum Tubing

Impurities	As Procured	After Four Runs in Vacuum
Oxygen	150 ppm	740 ppm
Carbon	50	
Nitrogen	50	70
Hydrogen	2	2
Niobium	100	
Iron	50	
Titanium	30	
Silicon	200	
Aluminum	50	
Other	100	

absorption of oxygen on tantalum has also been observed by Andrews.[8] The tantalum surface did not change appearance even though in some of the experiments tantalum was heated through four cycles during which measurements were taken.

The 39.1 w/o thorium-magnesium eutectic sample was placed in tantalum tubing and sealed under a partial atmosphere of helium. The current and potential leads were spot welded to the tantalum. The sample was heated to 700°C, cooled to 100°C, and reheated to above the melting point before data were taken.

During the test run the sample was heated to 920°C and cooled to 100°C. The sample was measured again to check the reproducibility of the data. For each point obtained the sample was heated until the system was at a steady state before data were taken. The resistance values obtained from one current direction were averaged with those obtained by reversing the current.

The resistance of the thorium-magnesium was calculated by subtracting the resistance of the tantalum at temperature from the total resistance shown in the following equation:

$$\frac{1}{R_{ThMg}} = \frac{1}{R_{Total}} - \frac{1}{R_{Ta}} .$$

The standard equation $\rho = \frac{RA}{L}$ was used to calculate the values for both solid and liquid eutectic, where L is the distance in centimeters measured between potential lead centers and A is the cross sectional area in square centimeters determined from measurements of the inside diameter of the tantalum tubes.

SUMMARY AND CONCLUSION

The electrical resistivity of solid 39 w/o thorium-magnesium was determined between room temperature and 400°C. Two rectangular bars of 70 and 67 mil cross section were used to obtain these data. The alloys had a high magnesium vapor pressure above 400°C. The resistivity of the alloy increased quite sharply above this point; therefore, only the resistivity values in tantalum were used, and are shown in Fig. 3.

The electrical resistivity of the molten 39 w/o thorium-magnesium alloy was determined between 589°C (its melting point) and 900°C. A sealed tantalum tube was used to contain the alloy as well as the magnesium vapor. The results of the solid alloy in tantalum agreed well with the results from the solid bars. The resistivity decreased as the temperature increased, similar to that for molten magnesium as reported by Freedman.[9]

It should be noted that tantalum tubing will absorb oxygen at these temperatures, even in a vacuum of 10^{-5} mm mercury, leading to changes in resistivity of as much as four microhm-centimeters.

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