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TEMPERATURE DEPENDENCES OF THERMAL AND ELECTRIC CONDUCTIVITY OF BRASS ALLOYS OF DIFFERENT ZINC CONCENTRATION IN THE TEMPERATURE RANGE 4–300 K

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Systematic measurements of the thermal and electric conductivity of eight brass samples having zinc concentration from 3% to 37% have been performed in the temperature range 4–300 K. The dependence of thermal conductivity of brasses on copper content in the alloy was found. The dependence of residual resistivity of brasses on zinc concentration was pointed out. The Matthiessen rule for the deviation of the ideal component of the electric resistivity of brass alloys was stated.

1. *Introduction*

This paper constitutes the continuation of investigations published in [1]. Investigations of the temperature dependence of thermal and electric conductivity of metals of different admixture concentration from $10^{-4}\%$ to $10^{-1}\%$ are quite widespread in scientific literature [2, 3]. But similar investigations of two-component alloys [4] are less numerous.

Measurements of the thermal conductivity of brasses available in scientific literature do not cover the whole range of zinc concentrations and the whole temperature range 4–300 K. There are a few measurements in the range 77–300 K.

The aim of this paper is the presentation of systematic research on the thermal and electric conductivity of brass alloys of different zinc concentration. Brass is considered to be representative of the two-component alloy.

2. *Experimental part*

2.1. The samples investigated

Eight samples of two-component brass of symbols M97*, M96, M90, M86*, M85, M70, M65* and M63 were examined. The number with M denotes approximate percentage of copper in the alloy. The samples designated by symbols M96, M90, M85, M70

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and M63 were obtained from smelting works after plastic working. The chemical analysis of copper concentration has been done at the Wrocław Institute of Technology. But spectral analysis to determine the kind and amount of admixture of other metals was performed at the Institute of Low Temperature and Structure Research in Wrocław. Zinc was the rest from 100%. The samples M97*, M86* and M65* were made from copper and zinc of purities 99.99% at the Institute of Nuclear Research in Świerk. These samples are characterized by the small amount of other admixtures and large grain structure (the size of the grain is about 10^{-2} mm). The samples having symbols M97*, M86* and M65* serve as a standard of a pure two-component alloy. The result of analysis of industrial samples and the certification of samples made at the Institute of Nuclear Research served for the preparation of Table I. An analysis of the chemical composition of samples was performed after their annealing. As is seen from Table I, other admixtures in industrial brasses do not exceed 1%.

TABLE I

Chemical composition of brass samples

Element	M97*	M96	M90	M86*	M85	M70	M65*	M63
Cu [%]	97.00	95.91	91.29	85.85	85.77	70.57	64.70	63.48
Zn [%]	3.00	3.28	7.94	14.15	13.43	28.73	35.30	36.27
the rest [%] (Fe, Ba, Bi, Si, Mg)	<0.01	0.81	0.77	<0.01	0.80	0.70	<0.01	0.25

Admixture elements not fulfil the criteria of Hume–Rothery as regard to copper, probably compose the inclusions in vacancies or interstitials of the crystal lattice of brass. In the course of the elaboration of the results, zinc and other elements in the investigated samples will be treated together as admixture atoms.

The residual electric resistivity ϱ_0 is the measure of material purity and it was decided to choose it as the arranging parameter. The resistivity ratio $R_{300}/R_{4.2}$ gives additional information about the purity of the material. Table II presents the mentioned characteristics of brass purity. Before measurements the samples were annealed in an atmosphere of argon at 650–700°C for two hours. Next, they were slowly cooled down to room tempera-

TABLE II

The resistivity ratio and residual resistivities of investigated brass samples

Quantity measured	M97*	M96	M90	M86*	M85	M70	M65*	M63
$\frac{R_{300}}{R_{4.2}}$	3.32	2.51	1.70	1.90	1.78	1.70	1.90	1.81
$\varrho_0 \cdot 10^6$ [Ω cm]	0.80	1.45	1.85	2.42	3.08	3.20	3.50	3.95

ture (the cooling time was about 30 hours). During annealing a slight sublimation of the zinc (about $5 \cdot 10^{-3}\%$ of the whole mass) took place. The aim of annealing was to achieve by the samples the phase equilibrium and also reduction of the dislocation number. The investigated brass samples were in the α phase and had the shape of rods, tube and metal plate of about 8 cm length.

2.2. The method of measurements, experimental set, the accuracy of measurements

The estimation of the thermal conductivity coefficient was based on the widely spread axial steady-state method of heat flux flowing along the sample. Two thermometers were used for reading the temperature difference.

The experimental arrangement cited in paper [1] is based on a metal cryostat and enables temperature regulation. The measurement chambers in the cryostat for the investigation of thermal and electric conductivity had their specific construction solutions.

The whole relative error of measurement of the thermal conductivity coefficient changed from about 9% at 4.2 K to 2.5% and 2% at 40 K and 70 K respectively, to about 1.7% at 300 K.

The error of measurement of the electric specific resistivity amounted to about 1.5% in the whole investigated temperature range.

2.3. The measurement results and discussion

In Fig. 1 the curves showing the dependence of thermal conductivity on temperature $\lambda(T)$ are presented for the temperature range 4–300 **K** for brass samples of zinc concentration from 3% to 37%. $\lambda(T)$ plots typical for alloys and setting in order parameter of family

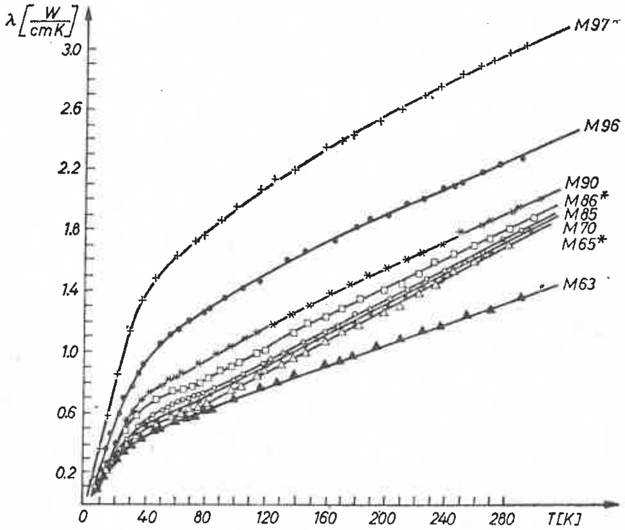

Fig. 1. The dependence of the thermal conductivity coefficient on temperature for brass samples of different zinc concentration

curves is zinc concentration. For the samples M86*, M85, M70 and M65* the inflexion point on the thermal conductivity curves were obtained in the temperature range 70–120 K.

Similar dependences with inflexions points were observed by the authors of paper [5] for some x concentration in the compound Na_xWo_3 and by the authors of paper [6] for Cu_3Au alloys. The suggestion was made that the observed by us anomaly is connected with the degree of change in arrangement in the CuZn alloy in the vicinity of the Cu_3Zn concentration. The measurements of heating curves and specific heat of brass samples were performed. The phase transition was not shown.

Fig. 2 demonstrates the character of the change of the thermal conductivity coefficient with respect to copper concentration in the alloy. The temperature is the parameter of the presented family of curves. The changing of copper concentration in the range from 97% to 86% causes a strong decreasing of the thermal conductivity coefficient λ of the alloy.

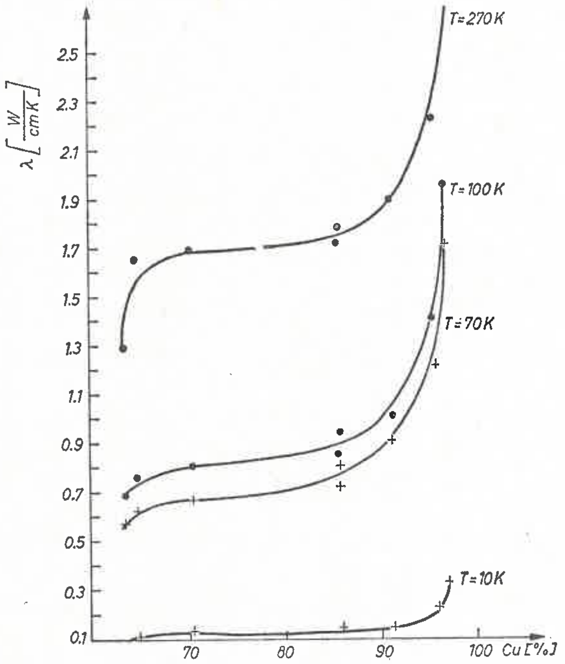

Fig. 2. The plot of the dependence of the thermal conductivity coefficient on copper concentration in a CuZn alloy for different fixed temperature values

Next diminishing the copper concentration to 70% has a weaker influence on the decrease of the λ value. In the range from 70% to 63% of copper concentration the strong decreasing of λ brasses takes part.

The λ dependence on copper concentration is larger if the temperature is higher. It is an interesting fact that λ values for the three CuZn samples (M97*, M86*, M65*) prepared from pure components (the level of admixture below 0.01%) lies on the same curves as the values for technical purity samples (admixture levels from 0.25% to 0.81%).

It results from the above mentioned facts that admixtures in brasses of technical purity do not play an important part in mechanisms of thermal conductivity. The change of admixture concentration from 0.001 % to several decimals of one percent causes the strong changing of thermal conductivity of a pure metal.

The difference in thermal conductivity of brasses for extreme values of Cu concentrations at 300 K is equal 2.0 W/cm K. This difference diminishes at 100 K to about 1.3 W/cm K and reaches the lowest value of about 0.2 W/cm K at temperature 4.2 K.

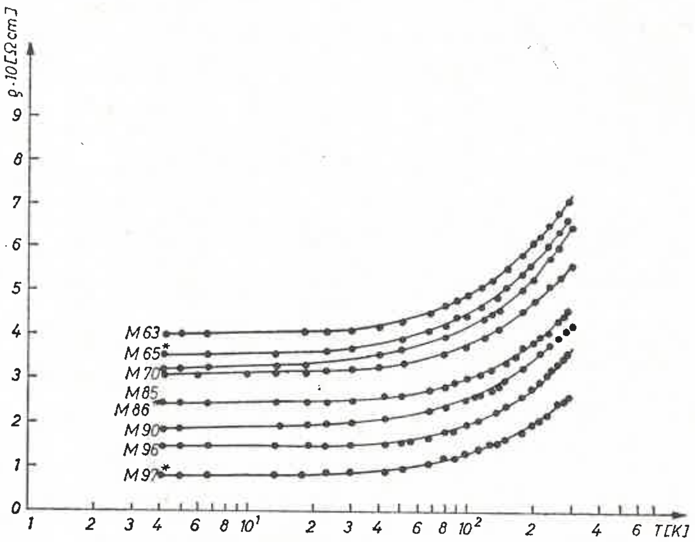

Fig. 3. The dependence of electric specific resistivity on temperature for brass samples of different zinc concentration in the alloy

In Fig. 3 the plot of the temperature dependence of specific electric resistivity for all eight investigated brass samples is presented. You can see on the graph the monotonic increase of electric resistivity of brass samples in the whole temperature range when the zinc concentration in the alloy is growing.

Fig. 4 shows the dependence of residual resistivity ϱ_0 on copper concentration in brass alloys. There may be seen the steep ϱ_0 dependence on copper concentration in the range from 100 % to 90 % and weaker dependence in the range from 85 % to 60 % of copper.

Fig. 5 presents the dependence of the ideal component of electric resistivity ϱ_i on temperature for pure copper [7] and for CuZn brasses. The parameter of the family of curves is the concentration of zinc in the alloy.

Fig. 5 shows the dependence of ϱ_i on zinc concentration. It means that deviation from the Matthiessen rule for electric conductivity takes place:

$$\varrho = \varrho_0 + \varrho_i. \tag{1}$$

No fulfilling of Eq. (1) was observed for example for zirconium doped with Ag, Cd, In, Sn [8] and for silver doped with Al, Mg, Cd [9]. According to Klemens [10] it may be connected with the change of band structure of the basis metal in the alloy.

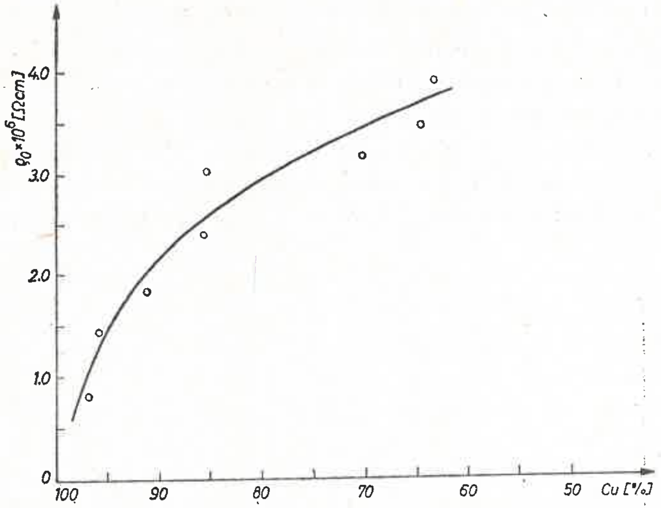

Fig. 4. The dependence of residual resistivity of brass samples on percentage concentration of copper

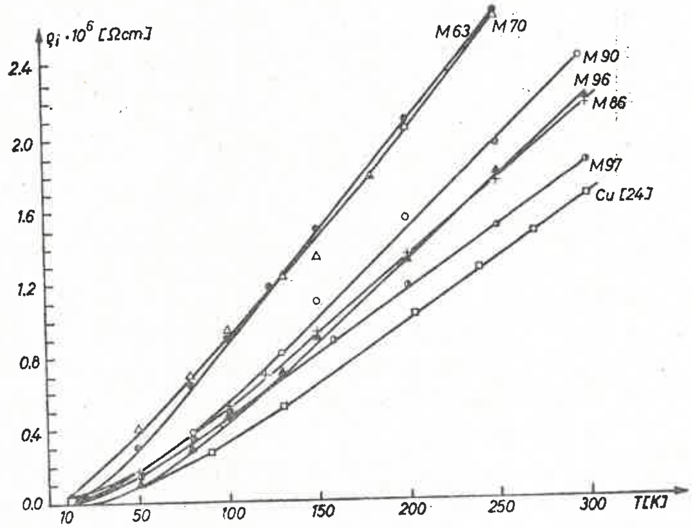

Fig. 5. The ideal component of electric resistivity for pure copper and CuZn alloys in dependence on temperature

3. Conclusions

The monotonic character of the change of thermal conductivity on temperature in the temperature range 4–300 K for eight brass samples with zinc concentration from 3% to 37% has been stated (Fig. 1). The observed small $\lambda(T)$ anomalies have not yet been explained.

It was shown that the thermal conductivity dependence of brass alloys on copper concentration is very steep for high temperature (270 K) and is very weak for low temperatures (10 K) (Fig. 2).

The monotonic plot of electric resistivity dependence on temperature for eight brass samples of different zinc concentration (Fig. 3) was confirmed. The electric resistivity of samples decreases with an increase of copper concentration in the alloy. The monotonic increase of the brass residual resistivity ϱ_0 accompanying the decrease of copper concentration in the alloy has been stated (Fig. 4). An especially steep change of ϱ_0 in the range of change of Cu concentration from 100% to 90% takes place.

The deviation from the Matthiessen rule for the ideal component of electric resistivity $\varrho_i(T)$ of brasses is shown in Fig. 5. In the range of low temperature the plots of $\varrho_i(T)$ for different zinc concentrations are very near each other but these differences grow with increasing temperature.

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