Archives of Materials Science and Engineering

Volume 44
Issue 1
July 2010
Pages 39-42

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Influence of iron on the surface tension of copper

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Received 13.04.2010; published in revised form 01.07.2010

ABSTRACT

Purpose: In the paper, the results of surface tension measurements at 1473 K and 1673 K with the use of sessile drop method, concerning liquid copper-iron alloys with 0.01 to 0.05 Fe molar fractions, are presented. The aim of the study was to determine the effects of iron and temperature on the surface tension of copper.

Design/methodology/approach: The experiments were conducted with the use of sessile drop method at 1473 K and 1673 K, in an argon atmosphere. For the investigations, a measuring apparatus PR-37/1600, produced by the Industrial Electronics Institute in Warsaw, was used. It consisted of a high-temperature pipe furnace, allowing the observation of a sample placed inside a horizontal reaction chamber (called a high-temperature microscope), and a camera, both coupled with a computer equipped with a program for the device work parameter control as well as for recording and analyzing pictures. The program was used for measurements of appropriate geometric parameters of liquid alloy drops which were necessary for surface tension evaluation. In order to determine the surface tension, a computational procedure, based on the least square estimation of the parameters of the differential equation system, was used, describing the shape of a sessile drop of liquid using coordinates of points placed along a curve that forms the outer contour of the drop cross-section.

Findings: The experiments showed that a higher Fe content in Cu-Fe alloys led to the increase in surface tension. A temperature rise of the investigated alloys, similarly for pure metals as well as a great majority of binary and multicomponent systems, is accompanied by the decrease in surface tension.

Practical implications: Surface tension has a significant impact on obtaining, refining and casting of metals and alloys. Thus, the knowledge of this parameter may be useful for both a description of phenomena that occur during these processes and their improvement.

Originality/value: The presented results may be the first literature data regarding surface tension of Cu-Fe alloys with 0.01 to 0.05 Fe molar fractions.

Keywords: Surface tension; Sessile drop; Copper; Cu-Fe alloys

Reference to this paper should be given in the following way:

B. Oleksiak, G. Siwiec, A. Blacha, J. Lipart, Influence of iron on the surface tension of copper, Archives of Materials Science and Engineering 44/1 (2010) 39-42.

PROPERTIES

1. Introduction

Together with density and viscosity, surface tension is a key parameter that describes a liquid phase and it has a major impact on processes occurring at metallurgical system interfaces. It determines, among others, reactions at metal-slag and metal-gas interfaces during metal production and processes which occur during removal of solid non-metallic inclusions from the melt as well as processes of metal and alloy refinement. Surface tension is also important for casting processes and composite material production. Furthermore, it has a significant effect on fireproof material corrosion.

Surface tension of liquid metals and alloys can be determined with the use of sessile drop method, pendent drop method, maximum bubble pressure method, drop weight method, detachment of thin plate (ring or cylinder) method or levitating drop method. An innovation is the use of immersion method, based on Archimedes' principle [1–4]. The analysis of surface tension measurement data regarding liquid metals and alloys listed by Keen [5], Niżjenko and Floka [6] and Siwiec and Botor [7] shows that among the above methods, the maximum bubble pressure and the sessile drop methods are most widely used for these investigations at high temperatures.

Iron is, together with lead, antimony or sulphur, an addition that always accompanies copper. The effect of Pb, Sb and S on surface tension of liquid copper was a subject of several publications [2, 3, 8, 9]. A Cu-Fe system was investigated by Brillo and Egry [10] as well as Nogi et al. [11]. However, the measurements performed by these authors only included alloys with high Fe content.

In the present paper, the results of surface tension measurements at 1473 K and 1673 K with the use of sessile drop method, concerning liquid copper-iron alloys with 0.01 to 0.05 Fe molar fractions, have been presented.

2. Methods and results

The experiments were conducted with the use of a measuring apparatus PR-37/1600, produced by the Industrial Electronics Institute in Warsaw. The program was used for measurements of appropriate geometric parameters of liquid alloy drops which were necessary for surface tension determination.

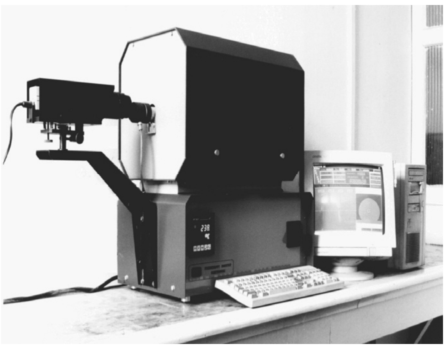

Fig. 1. The measuring equipment

A view of the measuring equipment is presented in Figure 1 and a schematic view of the apparatus is presented in Figure 2, Figure 3 shows a sample Cu-Fe drop shape, observed and recorded during the investigations.

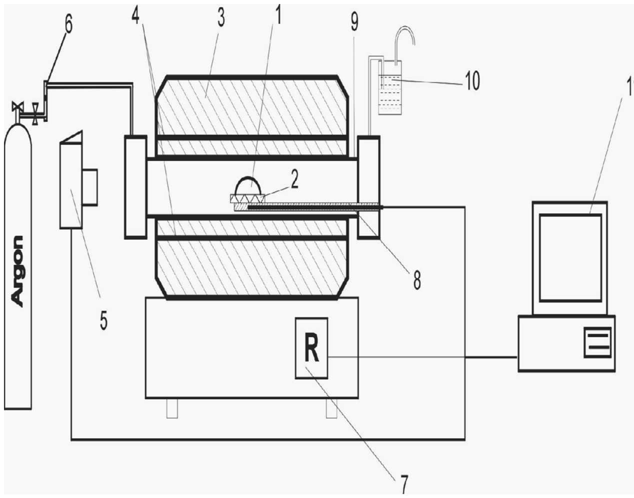

Fig. 2. Schematic view of measuring apparatus: 1 – drop of liquid metal, 2 – substrate, 3 – high temperature furnace, 4 – heating elements, 5 – CCD camera, 6 – gas delivery system, 7 – furnace work regulator, 8 – loading system with thermoelement, 9 – reactor, 10 – gas outlet system, 11 – PC computer

Fig. 3. An alloy drop of Cu – 0.01 X Fe at 1473 K

Copper and Cu-Fe samples (prepared with the use of M00B copper and analytically pure iron) were placed on Al_2O_3 substrates in the working chamber of high-temperature microscope. For the experiments, argon of 99.9999 % purity was used.

In order to determine the surface tension, a computational procedure, based on the least square estimation of the parameters b and B of the differential equation system, was used, describing the shape of a sessile drop of liquid with the use of coordinates of points placed along a curve that forms the outer contour of the drop cross-section. For calculations, the following equation system was use

$$\frac{d\phi}{ds} = \frac{2}{b} + B \cdot z - \frac{\sin\phi}{x} \quad (1)$$

$$\frac{dx}{ds} = \cos\phi \quad (2)$$

$$\frac{dz}{ds} = \sin\phi \quad (3)$$

where:

$$B = \frac{\rho g}{\sigma} \quad (4)$$

and

x – the horizontal coordinate of a point on the surface, measured downwards from the drop apex,
z – the vertical coordinate of a point on the surface, measured downwards from the drop apex,
ϕ - an angle, determined by the Z-axis and a line perpendiculars to the drop surface at a point described by (x, z) coordinates,
s – a length along the curve,
b – a radius of the curvature at the apex,
B – a coefficient of the drop shape,
ρ – liquid density,
g – gravity,
σ – surface tension.

Cu-Fe alloy densities at appropriate temperatures were determined with the use of additivity rule:

$$\rho = \sum_{i=1}^{2} \varphi_i \rho_i \quad (5)$$

where:

$$\varphi_i = \frac{X_i V_i}{\sum_{i=1}^{2} X_i V_i} \quad (6)$$

where:
φ_i – a volume fraction of an "i" component at the specified T - temperature,
X_i – a molar fraction of an "i" component of the alloy,
V_i – molar volume of an "i" component at the specified T temperature.

In Table 1, data necessary for determination of alloy density at the temperatures of surface tension measurements are presented (V_m represents the molar volume at the melting point).

A detailed description of the methods and the measuring equipment have been presented in the paper by Siwiec, Botor and Machulec [13].

Table 1.
Densities and molar volumes of liquid copper and iron [6,12]

Metal	ρ=f(T) g cm^{-3}	V_m cm^3 mol^{-1}	$\frac{1}{V_m}\frac{dV_m}{dT}\cdot 10^6$ K^{-1}
Cu	8.039-9.6·10^{-4}(T-1356)	7.91	100
Fe	6.99	7.96	-

In Table 2, the surface tension values, obtained during the copper and Cu-Fe alloy measurements, are presented. The columns include: 1– Fe content in the alloy; 2 – temperature of the measurements; 3 – density used for calculations; 4 – mean surface tensions, determined from six measurements, conducted in the same conditions; 5 – a standard deviation. Figure 4 shows a comparison of the surface tension isotherms of investigated alloys.

Table 2.
The surface tension of liquid copper and Cu-Fe alloys

X_{Fe}	T K	ρ=f(T) g cm^{-3}	σ N m^{-1}	S(σ)10^2 N m^{-1}
1	2	3	4	5
0	1473	7.93	1.304	0.7
	1673	7.73	1.240	0.9
0.01	1473	7.92	1.310	0.9
	1673	7.73	1.249	1.3
0.02	1473	7.91	1.355	1.8
	1673	7.72	1.271	1.2
0.03	1473	7.90	1.370	1.7
	1673	7.71	1.332	1.8
0.04	1473	7.89	1.408	0.8
	1673	7.71	1.354	0.7
0.05	1473	7.88	1.416	1.0
	1673	7.70	1.361	1.9

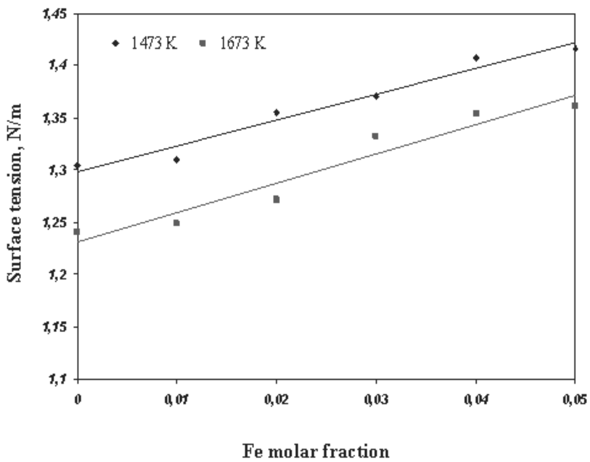

Fig. 4. Surface tension isotherms of Cu-Fe alloys at 1473 K and 1673 K

3. Conclusions

The experiments showed that a higher Fe content in Cu-Fe alloys led to the increase in surface tension. Surface tensions of alloys, containing 0.05 Fe molar fraction, are higher by over 0.1 N m^{-1} than the value for pure copper.

A temperature rise of the investigated Cu-Fe alloys, similarly for pure metals as well as a great majority of binary and multicomponent systems, is accompanied by the decrease in surface tension.

The results of the study may be useful for a description of phenomena that occur during processes of obtaining, refining and casting as well as improving of metals and alloys.

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