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SURFACE TENSION OF Cu – Bi ALLOYS AND WETTABILITY IN A LIQUID ALLOY – REFRACTORY MATERIAL – GASEOUS PHASE SYSTEM

NAPIĘCIE POWIERZCHNIOWE STOPÓW Cu – Bi ORAZ ZWILŻALNOŚĆ W UKŁADZIE: CIEKŁY STOP – MATERIAŁ OGNIOTRWAŁY – FAZA GAZOWA

The study involved measurements of surface tension of liquid binary copper-bismuth alloys with respect to their chemical composition and temperature as well as investigations of the liquid alloy – refractory material – gaseous phase system wettability using usual refractory materials, i.e. aluminium oxide, magnesium oxide and graphite. The experiments were performed with the use of sessile drop method and a high-temperature microscope coupled with a camera and a computer was utilised.

Keywords: surface tension, contact angle, wettability, sessile drop method, high-temperature microscope, liquid Cu-Bi alloys

W ramach pracy przeprowadzone zostały pomiary napięcia powierzchniowego ciekłych dwuskładnikowych stopów miedzi z bizmutem, w funkcji składu chemicznego i temperatury oraz badania zwilżalności w układzie: ciekły stop- materiał ogniotrwały-faza gazowa z wykorzystaniem typowych materiałów ogniotrwałych, to jest tlenku glinu, tlenku magnezu oraz grafitu. Badania wykonano metodą kropli leżącej, przy użyciu mikroskopu wysokotemperaturowego sprzężonego z kamerą i komputerem.

1. Introduction

Surface tension of liquid metals and alloys as well as wettability on a liquid-solid phase contact surface affect, among others, courses of phenomena at interfaces during pyrometallurgical processes of metal production and refinement as well as during casting processes. In addition, an important factor here is presence of surface-active substances in metals and alloys. These properties are observed for several elements, e.g. oxygen, sulphur, lead, antimony or selenium. Surface-active substances accumulate at interfaces and most commonly affect surface tension and contact angle values. For pyrometallurgical processes, they can influence their rates, usually through inhibition; however, there are cases when they increase rates of processes at interfaces. Surface tension and wettability also highly affect refractory material corrosion as well as they are important factors for processes of metal coating application, casting and composite material production [1-10]. At present, when metallurgical and casting modelling as well as material property modelling become increasingly popular, such parameters as surface tension, contact angles, density or viscosity of the liquid phase are of particular importance [11-15].

The study involved measurements of surface tension of liquid binary copper-bismuth alloys with respect to their chem-

ical composition and temperature as well as investigations of the liquid alloy – refractory material – gaseous phase system wettability using usual refractory materials, i.e. aluminium oxide, magnesium oxide and graphite.

2. Methodology

For the investigations of surface tension and wettability, copper-bismuth alloys, containing 1, 2, 3, 4, 5, 10, 20, 30, 40, 50 %mass Bi, were used. Samples of the above alloys were prepared to form cylinders of approximately 4 mm in diameter and height. For surface tension measurements, the samples were placed on 14 mm x 9 mm Al₂O₃ plates in the working chamber of a measuring device. For wettability investigations, MgO and graphite plates were also applied. As protective atmosphere during the experiments, argon 6.0 was utilised.

The investigations of surface tension and wettability were performed using the sessile drop method. A high-temperature microscope coupled with a camera and a computer was applied. The sample images were displayed on the screen and recorded by the computer, which ensured that measurements of relevant geometrical parameters of the liquid metal or alloy drop and determination of surface tension and contact angle

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could be subsequently performed. A detailed description of the measuring equipment and measurement methods is presented in several already published papers [1, 2, 14-17].

The surface tension and wettability investigations were conducted at 1373, 1423, 1473, 1523 and 1573 K.

3. Study results

Results of the surface tension measurements for liquid copper-bismuth alloys of maximum 50 %mass Bi content are presented in Table 1. Results of the contact angle measurements for the liquid alloy – refractory material – gaseous phase system are presented in Tables 2-4.

cd. TABLE 1

1	2	3	4
30	1373	8156	481
	1423	8104	466
	1473	8053	459
	1523	8001	449
	1573	7950	432
40	1373	8228	454
	1423	8176	440
	1473	8124	444
	1523	8072	432
	1573	8019	430
50	1373	8315	453
	1423	8263	437
	1473	8210	420
	1523	8157	420
	1573	8104	415

TABLE 1

Results of the liquid Cu-Bi alloy surface tension measurements

Bi content, %mass	Temperature, K	Density, kg·m ⁻³	Surface tension, mN·m ⁻¹
1	2	3	4
1	1373	8004	1295
	1423	7954	1285
	1473	7904	1274
	1523	7854	1268
	1573	7803	1255
2	1373	8008	1193
	1423	7956	1186
	1473	7906	1178
	1523	7858	1133
	1573	7808	1125
3	1373	8012	1107
	1423	7962	1099
	1473	7912	1086
	1523	7862	1071
	1573	7812	1059
4	1373	8016	994
	1423	7956	967
	1473	7916	961
	1523	7866	953
	1573	7816	936
5	1373	8021	791
	1423	7971	786
	1473	7920	774
	1523	7870	769
	1573	7820	773
10	1373	8044	738
	1423	7993	731
	1473	7943	722
	1523	7893	718
	1573	7842	713
20	1373	8095	670
	1423	8044	660
	1473	7993	616
	1523	7943	608
	1573	7892	606

TABLE 2

Results of the contact angle measurements for the liquid copper-bismuth alloy – aluminium oxide – gaseous phase system

Bi content, %mass	Temperature, K	Contact angle, °
1	2	3
1	1373	140
	1423	139
	1473	139
	1523	138
	1573	138
2	1373	139
	1423	138
	1473	137
	1523	137
	1573	136
3	1373	137
	1423	136
	1473	136
	1523	136
	1573	135
4	1373	137
	1423	136
	1473	136
	1523	136
	1573	135
5	1373	136
	1423	135
	1473	135
	1523	135
	1573	135
10	1373	134
	1423	134
	1473	133
	1523	132
	1573	132

cd. TABLE 2

1	2	3
20	1373	134
	1423	133
	1473	133
	1523	132
	1573	131
30	1373	134
	1423	134
	1473	134
	1523	133
	1573	132
40	1373	125
	1423	123
	1473	122
	1523	120
	1573	119
50	1373	123
	1423	121
	1473	120
	1523	118
	1573	116

cd. TABLE 3

1	2	3
10	1373	123
	1423	123
	1473	123
	1523	122
	1573	122
20	1373	122
	1423	122
	1473	122
	1523	122
	1573	121
30	1373	122
	1423	122
	1473	121
	1523	121
	1573	121
40	1373	120
	1423	120
	1473	120
	1523	119
	1573	119
50	1373	119
	1423	119
	1473	118
	1523	117
	1573	117

TABLE 3

Results of the contact angle measurements for the liquid copper-bismuth alloy – magnesium oxide – gaseous phase system

Bi content, %mass	Temperature, K	Contact angle, °
1	2	3
1	1373	125
	1423	125
	1473	124
	1523	124
	1573	125
2	1373	123
	1423	123
	1473	122
	1523	120
	1573	120
3	1373	123
	1423	123
	1473	123
	1523	122
	1573	122
4	1373	123
	1423	122
	1473	122
	1523	121
	1573	120
5	1373	123
	1423	123
	1473	122
	1523	120
	1573	120

TABLE 4

Results of the contact angle measurements for the liquid copper-bismuth alloy – graphite – gaseous phase system

Bi content, %mass	Temperature, K	Contact angle, °
1	2	3
1	1373	140
	1423	138
	1473	138
	1523	137
	1573	137
2	1373	141
	1423	141
	1473	140
	1523	140
	1573	140
3	1373	140
	1423	139
	1473	140
	1523	140
	1573	139
4	1373	138
	1423	138
	1473	138
	1523	138
	1573	138

cd. TABLE 4

1	2	3
5	1373	135
	1423	134
	1473	133
	1523	133
	1573	133
10	1373	135
	1423	135
	1473	132
	1523	132
	1573	132
20	1373	127
	1423	125
	1473	123
	1523	122
	1573	122
30	1373	120
	1423	120
	1473	120
	1523	119
	1573	118
40	1373	119
	1423	119
	1473	119
	1523	119
	1573	119
50	1373	118
	1423	118
	1473	116
	1523	115
	1573	114

4. Summary

The results of measurements of liquid Cu-Bi alloy surface tension have revealed a significant effect of the bismuth additive on the parameter values. In copper, bismuth acts as a surface-active substance like e.g. oxygen, sulphur or lead. A slightly increased Bi fraction in the Cu-Bi alloy leads to a markedly reduced surface tension, which is illustrated by the Cu-Bi surface tension values in Table 1. When the bismuth fraction in the alloy is 40 %mass and higher, the surface tension is near the value for pure bismuth. This may suggest accumulation of Bi at the liquid alloy-gaseous phase interface as for other known surface-active substances. The temperature rise causes a linear decrease in the surface tension of Cu-Bi alloys.

The wettability investigations for the liquid copper-bismuth alloy – refractory material – gaseous phase system show that this element causes reduction in the values of contact angles at Al₂O₃, MgO and graphite surfaces. For these alloys, the effect of temperature rise on the above material wettability improvement is also observed.

While analysing the results of wettability studies on liquid metal (alloy) – solid metal oxide obtained by Najdicz [5] and considering his wettability theory, it can be assumed that the investigated Cu-Bi alloys, when in contact with other thermodynamically stable oxides (e.g. CaO, ZrO₂, SiO₂), will show a similar behaviour to that observed for aluminium and magnesium oxides.

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