S. KORDASZEWSKI, P. KWAŚNIEWSKI, G. KIESIEWICZ, K. FRANCZAK,
W. ŚCIĘŻOR, R. KOWAL, P. STRZĘPEK

ISSN 0543-5846
METABK 61(3-4) 619-621 (2022)
UDC – UDK 669.35.5.24.782:669-66.091:66.04:620.178.1:537.311.3=111

OPTIMALIZATION OF THE METALLURGICAL SYNTHESIS PARAMETERS OF CUZN37 BRASS WITH NICKEL AND SILICON ALLOY ADDITIVES

Received – Primljeno: 2021-10-22
Accepted – Prihvaćeno: 2022-03-03
Original Scientific Paper – Izvorni znanstveni rad

The modifying possibility of the commercial CuZn37 brass (M63) with nickel and silicon is being discussed throughout the article. The proposed alloy additives made it possible to improve the commercial brass properties by precipitation hardening, thus making it extremely competitive in comparison to base material. The study also discussed the conditions (temperature and time) of the metallurgical synthesis and its influence on the weight percentage of not only proposed alloy additives but also the amount of zinc loss from the commercial brass due to the evaporation during the metallurgical processes.

Keywords: CuZn37-Ni-Si alloy, metallurgical synthesis, heat treatment, hardness parameters, electrical conductivity

INTRODUCTION

The alloys of copper and zinc (commonly known as brasses) were the search result for the substitute alloys for tin bronzes and lead bronzes as the former suffer from the deficit of the main alloy additive and the use of the latter became limited due to the guidelines of EU directive regarding the restriction of the use of hazardous substances [1,2].

The typical zinc addition to copper ranges from 10 and 50 wt. % as higher content makes causes brittleness in brasses. The addition of zinc has a significant impact on the technological, mechanical, electrical and physical properties of the discussed alloys (see Figure 1) [3].

Depending on the used alloy additives the strength properties of brasses (*R*m) may vary from 250 to even 750 MPa and electrical conductivity ranges from 3 to 15,6 MS/m. Selected brass grades commonly used in everyday industry along with mechanical and electrical properties were presented collectively in Table 1.

Table 1 **Properties of selected, typical brass grades [3-10]**

Alloy	*R*m / MPa	*R*0,2 / MPa	*A* / %	γ / MS/m
CuZn37	275-600	70-550	10-30	13,0-15,6
CuZn39Pb2	250-560	120-510	12-15	13,9-15,5
CuZn28Sn	365-669	124-496	4-69	14,5
CuZn16Si4 (MK80)	400-500	230-300	8-30	3-6

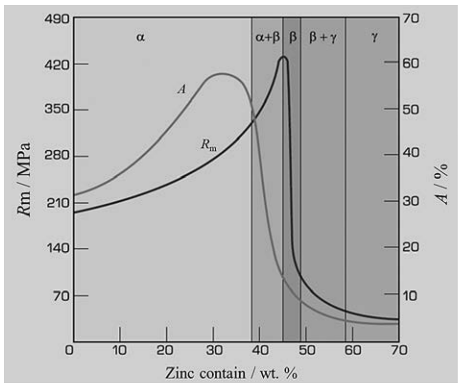

Figure 1 *R*m / MPa and elongation *A* / % of brass in the function of zinc content / wt. % [1]

EXPERIMENTAL PROCEDURE

The charge material for the conducted research was CuZn37 (M63) in the form of qualified scrap. Generally the alloy in question does not respond to heat treatment, however, based on the accessible literature it is postulated that the addition of nickel and silicon to CuZn37 forms a new alloy with prospective precipitation hardening possibilities as the brass-based material with numerous precipitation of Ni_2Si (Figure 2) [11-13]. The Cu-Ni_2Si phase diagram presented at Figure 3 suggests that the appropriate Ni and Si content in Cu creates material susceptible to heat treatment.

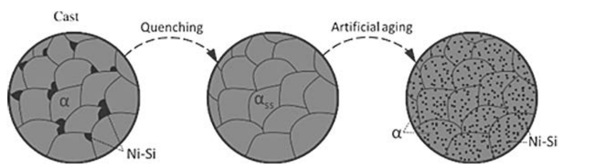

Figure 2 The concept of CuZn37 with the alloy additives of Ni and Si

S. Kordaszewski (e-mail: szyk@agh.edu.pl), P. Kwaśniewski, G. Kiesiewicz, K. Franczak, W. Ścięzor, R Kowal, P. Strzępek, University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

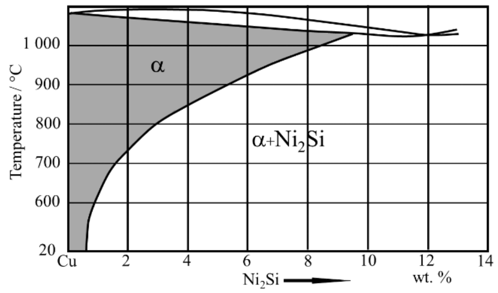

Figure 3 Cu-Ni_2Si phase diagram [10, 11]

Initial heat treatment research

Initial research works on the possibility of introducing alloy additives of Ni and Si to CuZn37 brass and therefore obtaining a new alloy susceptible to heat treatment were conducted. CuZn37 brass scrap material with a defined chemical composition in compliance with EN-1982:2017 standard, pure nickel with minimum of 99,95 wt. % of Ni and pure silicon with minimum of 99,5 wt. % of Si, both in compliance with proper standards. Metallurgical synthesis of CuZn37 brass with alloy additives was conducted in a graphite crucible as it has been proven not to be wettable by copper and copper alloys [14]. The process was carried out in a resistance furnace at 1 200 °C temperature for 1,5 hour, thus obtaining materials with chemical compositions as presented in Table 2. Each of the obtained materials was subjected to further homogenization and supersaturation process followed by artificial aging. The parameters of the metallurgical synthesis and heat treatment were collectively presented in Table 3.

Each of the research stages presented in Table 3 were followed by electrical conductivity and hardness tests. Electrical conductivity was determined with using eddy current method on SigmaTest 2.069 device with the measuring range of 0,5 MS/m and 65 MS/m (i.e. from 1 % to 112 % IACS), the accuracy of +/- 0,5 % and the resolution of +/- 0,1 % at 60 kHz. Vickers hardness was determined using Tukon2500 device with the load range of 10 gf to 50 kgf, a force measurement error of +/- 1,5 % below 200 g and +/- 1 % above 200 g. The research was conducted with 10 kgf and load time of 10 s.

Table 2 **Chemical composition of the obtained alloys / wt. %**

Alloy	Cu	Zn	Ni	Si	Other
CuZn37	63,14	36,78	00,1	0,00258	0,07364
CuZn37 Si0,5	62,52	36,9	0,01	0,5136	0,0564
CuZn37 Ni0,5	61,67	37,75	0,4707	0,0398	0,0695
CuZn37 Ni0,5Si0,5	61,92	37,12	0,4546	0,4322	0,0732

Table 3 **Parameters of the metallurgical synthesis and heat treatment**

Research stage	Time	Temperature
Metallurgical synthesis	1,5 h	1 200 °C
Quenching	5 h	700 °C
Artificial aging	1 h	400 °C
	3 h	400 °C
	5 h	400 °C

Research on the metallurgical synthesis parameters – zinc evaporation

The first stage of the research was focused on the zinc evaporation during metallurgical synthesis processes (melting and alloying). Initially research was conducted on CuZn37 brass scrap which was held in the liquid state in 1 100 °C, 1 150 °C and 1 200 °C for 2 hours. Further research included materials with Ni (1 wt. %) and Si (0,5 wt. %). Extensive research with target alloy were conducted with a wider range of temperatures (1 050 °C – 1 200 °C every 50 °C) and between 0,5 h and 2 h every 0,5 h.

Research on the metallurgical synthesis parameters – alloying of Ni and Si

The research on the target alloy (CuZn37 with Ni and Si alloy additives) was conducted in analogical conditions in terms of temperature and time as described above. The aim of the research was determination of the favourable metallurgical synthesis parameters that would allow obtaining of the intended values of Ni (1 wt. %) and Si (0,5 wt. %) in CuZn37 alloy.

RESULTS AND DISCUSSION

Initial heat treatment research

The obtained results presented at Figure 4 confirmed that neither CuZn37 with only Ni nor CuZn37 with only Si may be subjected to precipitation hardening.

However, it was proven that when both alloy additives are added to CuZn37 the obtained alloy shows the effect of precipitation hardening as a result of heat treatment. After only 1 hour of artificial aging the hardness of the obtained CuZn37Ni1Si0,5 alloy increases from approx. 110 HV10 to approx. 126 HV10 with simultaneous increase of the electrical conductivity from approx. 11,8 MS/m to approx. 12,5 MS/m which indicates that Ni_2Si phase have precipitated from the solid solution.

Zinc evaporation

The research on zinc evaporation proved that when the temperature of furnace was set to 1 200 °C only when the liquid metal was exposed to high temperature for 0,5 h it did not exceed the zinc evaporation of 2 wt. % which is a generally accepted standard. For 1 150 °C

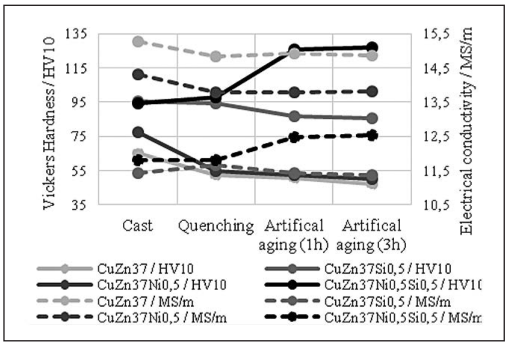

Figure 4 The heat treatment influence on the electrical conductivity and Vickers hardness of the obtained alloys

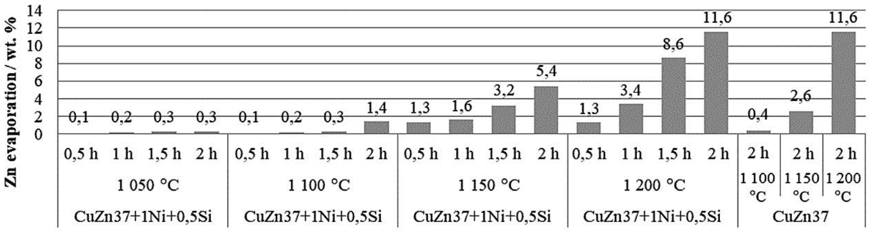

Figure 5 Zinc evaporation due to metallurgical synthesis processes

the time could be increased to 1 h and with lower temperatures none of the tested times exceeded the 2 wt. % limit of zinc evaporation. Out of the 16 variants of time and temperature 2 wt. % of zinc evaporation was not exceeded for 11 of them – Figure 5.

Research on metallurgical synthesis

A wide range of time and temperature variants of metallurgical synthesis and their influence on the wt. % content of Ni and Si in the CuZn37Ni1Si0,5 alloy was presented collectively in Table 4.

Table 4 **Obtained contents of Ni and Si in the CuZn37 alloy / wt. %**

Time / Temp.	0,5 h	1 h	1,5 h	2 h	Alloy additive
1 050 °C	0,53	0,82	0,84	0,84	Ni
	0,36	0,30	0,39	0,34	Si
1 100 °C	0,66	0,86	0,89	0,91	Ni
	0,37	0,42	0,38	0,43	Si
1 150 °C	0,93	0,91	0,97	1,01	Ni
	0,38	0,42	0,45	0,45	Si
1 200 °C	0,92	0,94	1,04	1,12	Ni
	0,40	0,45	0,48	0,50	Si

Out of the 16 variants of metallurgical synthesis only 5 fulfilled the expected amount of Ni (expected at least 0,95 wt. % of Ni) and Si (expected at least 0,45 wt. % of Si). These were the temperature of 1 200 °C with the metallurgical synthesis times of 1, 1,5 and 2 hours and for 1 150 °C with the metallurgical synthesis times of 1,5 and 2 hours. These are, however, the times and temperatures where the evaporation of zinc exceeded the standardized 2 wt. % of loss.

CONCLUSIONS

On the basis of the conducted research it may be stated that:

Simultaneous addition of Ni and Si to the commercial brass alloy CuZn37 (M63) allows the obtaining of the entirely new alloy which properties may be improved with the heat treatment and activating precipitation hardening.

Further research was devoted to defining of the optimal parameters of the metallurgical synthesis of CuZn37 brass alloy with alloy additives of Ni and Si carried out in the resistance furnace. Zinc evaporation is a substantial, serious and inevitable issue. Obtaining brass alloy with simultaneously expected wt. % of Ni and Si alloy additives requires the process to be conducted either high temperature or long time of the synthesis which results in significant zinc evaporation and as such requires for a compromise to be made. As the main objective is to obtain a desired chemical composition with possibility of alloying additional zinc lost due to evaporation the guidelines for the metallurgical synthesis parameters using resistance furnace were defined at 1 150 °C with 1,5 hour of alloying time.

The conducted study provides basic knowledge for prospective further research aimed at developing of a new brass-based alloy with an optimal range of Ni and Si alloy additives along with the selection of the heat treatment parameters of the said alloys.

REFERENCES

[1] N. Ninan, S.V.S. N. Murty, S. Manwatkar, P. R. Narayanan, Failure analysis of cracked brass turrets used in electronic circuits, Engineering Failure Analysis 2 (2014) 107-117

[2] F. Schultheiss, D. Johansson, V. Bushlya, J. Zhou, K. Nilsson, J.-E. Ståhl , Comparative study on the machinability of lead-free brass, Journal of Cleaner Production (2017) 149 C 366-377

[3] L. Dobrzański, Podstawy nauki o materiałach i metaloznawstwo, 2002

[4] Standard PN-EN 1652:1997 – Miedź i stopy miedzi: Płyty, blachy, taśmy i krążki ogólnego przeznaczenia

[5] Standard EN 12166 Copper and copper alloys: Wire for general purposes

[6] Standard PN-EN 12167 (E) Miedź i stopy miedzi: Kształtowniki i pręty prostokątne ogólnego przeznaczenia”

[7] P. Strzępek, A. Mamala, M. Zasadzińska, K. Franczak, B. Jurkiewicz, Research on the drawing process of Cu and CuZn wires obtained in the cryogenic conditions, Cryogenics 100 (2019), 11-17

[8] J. R. Davis, Copper and copper alloys, ASTN International Handbook Committee, 2001.

[9] Standard EN-1982:2017 (E): Miedź i stopy miedzi

[10] Standard EN 12166 Copper and copper alloys: Wire for general purposes

[11] A. Bögel, TEM-Untersuchungen an höherfesten und elektrisch hochleitfähigen CuNi2Si-Legierungen, Metall-Forschung 63, (2009)

[12] P. Kwaśniewski, Nośno-przewodzący osprzęt górnej kolejowej sieci trakcyjnej, Materiały – Konstrukcje - Technologie Wytwarzania (2016)

[13] W. Gluchowski, Z. Rdzawski, J. Sobota, J. Domagala-Dubiel, Effect of the combined heat treatment and severe plastc deformation on the microstructure of CuNiSi alloy, Archives of metallurgy and materials 61 2 (2016) 1207-1214

[14] M. Poręba, T. Kubaszek, M. Góral, B. Koscielniak, K. Gancarczyk, M. Drajewicz, The Formation of Columnar YSZ Ceramic Layer on Graphite by PS-PVD Method for Metallurgical Applications, Solid State Phenomena 320 (2021), 49-54

Note: The translator responsible for English language: Andrzej Mamala, AGH University of Science and Technology, Kraków, Poland