ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 11
Special Issue
3/2011

261 – 264

45/3

Structure and selected properties of high-aluminium Zn alloy with silicon addition

A. Zyska*, Z. Konopka, M. Łągiewka, M. Nadolski
Department of Foundry, Technical University of Częstochowa,
ul. Armii Krajowej 19, 42-200 Częstochowa, Polska
*Corresponding author. E-mail address: zyska@mim.pcz.czest.pl

Received 20.07.2010; accepted in revised form 27.07.2011

Abstract

The results of examinations concerning the abrasive wear resistance, hardness, and thermal expansion of high-aluminium zinc alloys are presented. The examinations were carried out for five synthetic ZnAl28 alloys with variable silicon content ranging from 0.5% to 3.5%, and – for the purpose of comparison – for the standardised ZnAl28Cu4 alloy. It was found that silicon efficiently increases the tribological properties and decreases the coefficient of thermal expansion of zinc alloys. The most advantageous set of the examined properties is exhibited by the alloys containing over 2.5% Si. They are characterised by higher parameters as compared with the standardised alloy. Observations of microstructures reveal that silicon precipitates as a separate compact phase, and its morphology depends on the Si content in the alloy. The performed examinations show that silicon can satisfactorily replace copper in high aluminium Zn alloys, thus eliminating the problem of dimensional instability of castings.

Keywords: ZnAl alloys, Structure, Tribological properties, Thermal expansion

1. Introduction

Zinc alloys with increased aluminium content are frequently used materials for sleeves of plain bearings. They exhibit good tribological, mechanical, and technological properties and low melting point. Bearings made of these alloys can work under the load of up to 20 MPa at low and medium circumferential speeds and the temperature not exceeding 100°C, and can replace bearings made of tin bronzes in the non-corrosive environments [1-10]. The main addition to the ZnAl alloys is copper, which influence advantageously their abrasive wear resistance, strength, and hardness, but causes a large dimensional instability of castings. The dimensional changes occur already at 0.6÷0.7% copper addition and increase with an increase of the considered element amount [7, 11-14]. Dimensional instability is related to the phase transitions proceeding in solid state and to the occurring of complex ZnCu phases [7, 13, 15]. Therefore investigations are carried out in order to replace Cu with other elements, which can provide for high tribological and mechanical properties of the binary ZnAl alloys, and simultaneously prevent dimensional instability [4, 5, 10]. Reference [16] presents thorough examinations of properties of ZnAl40 alloy with silicon addition, which solves the problem of dimensional changes of castings though do not enhance strength to a great degree. Results of these examinations indicate that the enriching of ZnAl alloy with silicon increases hardness and abrasive wear resistance, while the coefficient of friction and density are reduced. It is also concluded that the high-aluminium zinc alloys with silicon addition are better materials for plain bearings than non-silicon alloys [16].

The present investigations are aimed to an assessment of structure and selected technological properties of ZnAl28 alloy with silicon addition content ranging from 0.5% to 3.5%, as well as of the standardised ZnAl28Cu4 alloy for the purpose of comparison.

2. The material and the method of examination

The examinations were carried out for five synthetic zinc alloys (Table 1) and the standardised ZnAl28Cu4 alloy (according to PN-EN 12844). The considered alloys were melted in the induction medium frequency furnace in steel crucibles with graphite coating. Specimens were die cast in the shape of cylinders with 40 mm diameter. The pouring temperature was equal to 540°C, and the die temperature 150°C. The cast specimens were examined with respect to their tribological properties, thermal expansion and microstructure. The abrasive wear resistance tests were performed in the roll-and block system under conditions of dry friction by means of the T-05 tribological tester. The abraded specimens were 15.75×10×6.35 blocks, while the counter-piece was a roll of 35 mm diameter made of NC10 steel. The values of coefficients of thermal expansion of the examined alloys were measured for specimens of 6 mm diameter and 35 mm length by means of DA-3 dilatometer. The examined range of temperature was 50°C to 250°C. Specimens were heated and cooled at a rate of 1 K/s, and the records of temperature and length were taken every one second. Microstructure was observed by means of Nikon Epiphot light microscope on samples taken from the middle parts or castings.

Table 1.
Basic chemical composition of the examined alloys

Type of alloy	Quantity of element, %			
	Zn	Al	Si	Cu
ZnAl28Cu4	68	28	-	4
ZnAl28	72	28	-	-
ZnAl28Si0.5	71.5	28	0.5	-
ZnAl28Si1.5	70.5	28	1.5	-
ZnAl28Si2.5	69.5	28	2.5	-
ZnAl28Si3.5	68.5	28	3.5	-

3. Results and an analysis of examinations

The structure of standardised ZnAl28Cu4 alloy presented in Fig. 1 consists of the Al-rich β phase, Zn-rich η phase, and Cu-rich ε phase. The basic structural elements are dendrites of β phase, among which both the binary eutectic (β + η) and the ternary eutectic (β + η + ε) solidify. The structure of the non-silicon ZnAl27 alloy is quite similar, and also consists of primary β phase crystals, but the interdendritic spaces are filled with (β + α) eutectoid (Fig. 2). Silicon precipitates appear in the alloys containing Si addition, their shape and size being dependent on the quantity of this element. If this quantity is low, 0.5% or 1.5%, there occur numerous, very tiny globular or acicular precipitates (Figs 3, 4). In alloys with greater silicon content these precipitates are significantly larger and take the shape of grains with sharp edges (Figs 5, 6). The shape and the size of silicon crystals are similar to those observed in hypereutectic silumins.

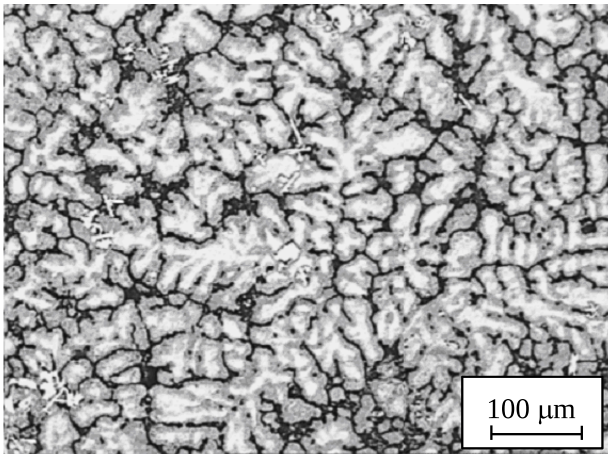

Fig. 1. Structure of ZnAl28Cu4 alloy, etched with Nital

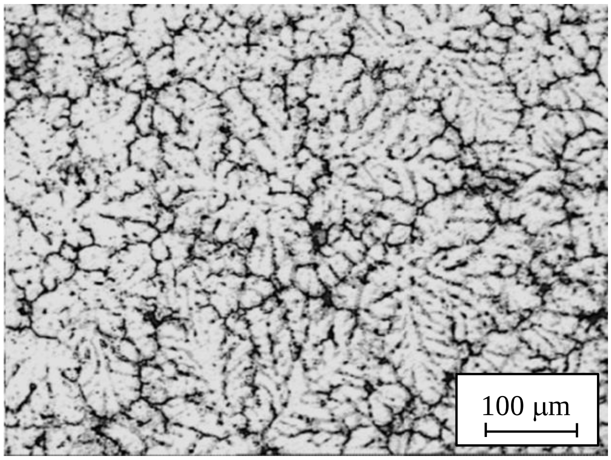

Fig. 2. Structure of ZnAl28 alloy, etched with Nital

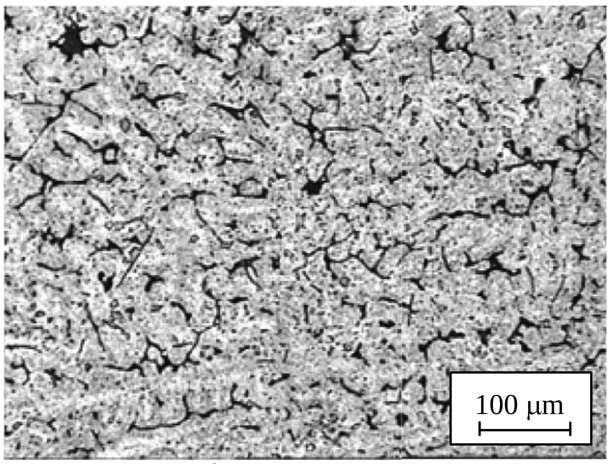

Fig. 3. Structure of ZnAl28Si0.5 alloy, etched with Nital

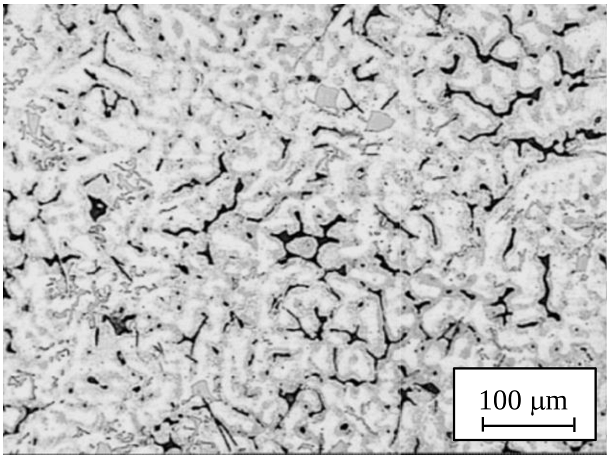

Fig. 4. Structure of ZnAl28Si1.5 alloy, etched with Nital

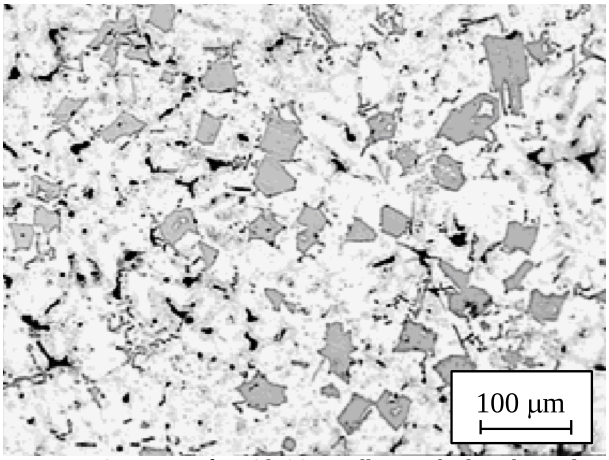

Fig. 5. Structure of ZnAl28Si2.5 alloy, etched with Nital

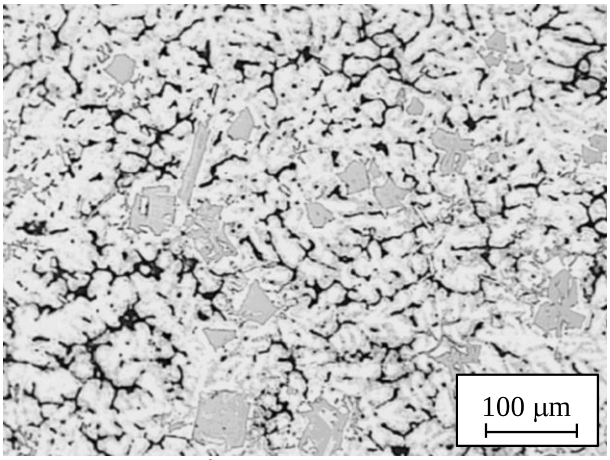

Fig. 6. Structure of ZnAl28Si3.5 alloy , etched with Nital

Figure 7 presents the abrasive wear of ZnAl alloys versus the silicon content and compares it with the abrasive wear of the standardised ZnAl28Cu4 alloy. The measurements show that ZnAl alloys enriched with silicon increase their abrasive wear resistance nearly by three times. The significant increase of abrasive wear resistance occurs already for silicon content as small as 0.5%. On the other hand, increasing silicon content over 1.5% do not further influence the abrasive wear resistance, except that for the alloy with 2.5% Si content the mass decrement is somewhat larger than that for alloys with 1.5% Si or 3.5% Si. The performed examinations confirm that copper can be satisfactorily replaced with silicon with respect to the tribological properties of materials.

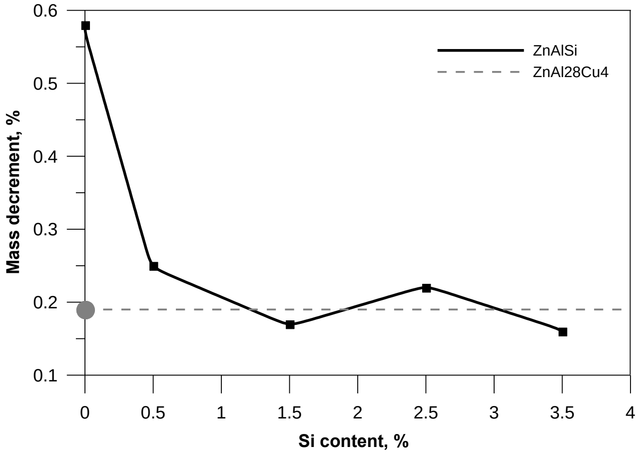

Fig. 7. Abrasive wear resistance of ZnAl alloys versus the silicon content

The results of examinations illustrated in Figure 8 indicate that the addition of silicon to the ZnAl alloy results also in a significant increase in its hardness. A small amount of this element (0.5%) rises the alloy hardness by about 20%. The highest hardness values are achieved in alloys containing over 2.5% Si. These alloys exhibit hardness exceeding by about 10% the HB value of the comparative standardised alloy.

Figure 9 presents characteristics of thermal expansion of the considered ZnAl alloys. It shows that the coefficient of thermal expansion decreases with an increase in silicon content in the alloy, and the highest drop rate occurs in the range 0.5÷2.5% Si. Higher silicon contents do not cause changes of such significance. It also results from the performed measurements that alloys containing the addition of over 2% Si are characterised by lower thermal expansion than the standardised ZnAl28Cu4 alloy. Taking additionally into account that silicon does not undergo any phase transitions in solid state, one can conclude that it significantly increases the dimensional stability of castings made of ZnAl alloys.

The presented initial results of investigations in the field of high aluminium zinc alloys point out that silicon can be an alternative element to copper. Further thorough investigations are however required to determine precisely the possibilities and advantages resulting from the replacement of copper with silicon in the considered alloys.

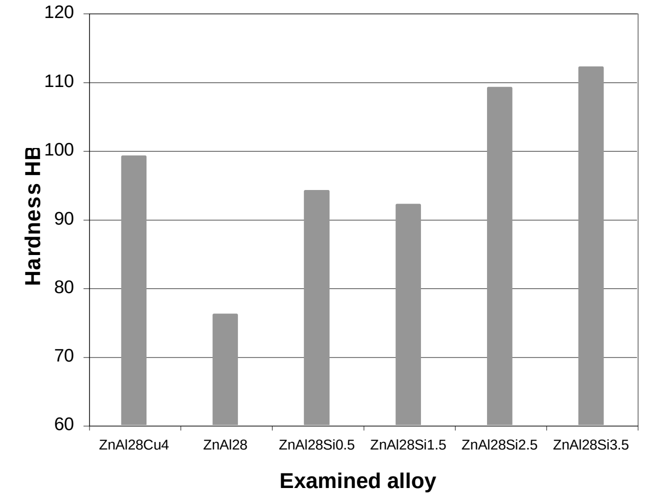

Fig. 8. Comparison of average hardness values measured for the examined alloys

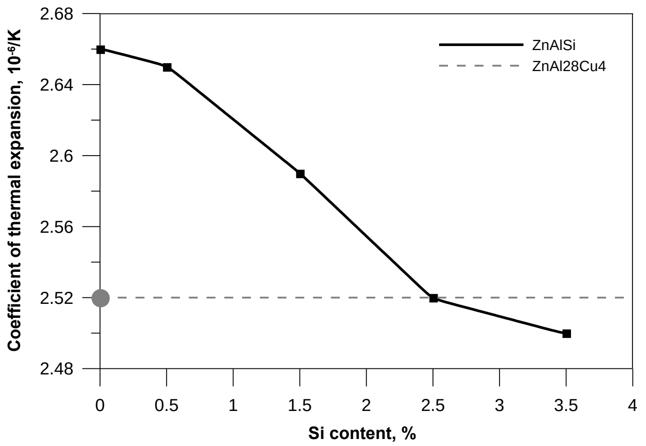

Fig. 9. Changes in the coefficient of thermal expansion of ZnAl alloys versus silicon content

4. Final conclusions

1. Silicon added to the ZnAl28 alloy (≥ 2.5% Si) precipitates as a distinct grain phase uniformly distributed within the matrix volume.
2. Heterophase structure of ZnAlSi alloys provides for high hardness and abrasive wear resistance.
3. The most advantageous set of examined properties occurs in alloys containing 2.5% or 3.5% silicon. For these silicon content values the achieved hardness and abrasive wear resistance are higher, and the coefficient of thermal expansion is lower, than in the standardised ZnAl28Cu4 alloy.
4. The performed examination point out that copper in the high aluminium zinc alloys intended for plain bearings can be satisfactorily replaced with silicon, which does not undergo any phase transitions in solid state and do not cause dimensional changes of castings during their work.

References

[1] E. Gervais, H. Levert, M. Bess, The development of a family of zinc-based foundry alloys, Trans. Am. Foundrym. Soc. 88 (1980) 183–194.

[2] E. J. Kubel, Expanding horizons for ZA alloy, Adv. Mater. Proc., 132 (1987) 51-57.

[3] M.J. Barber, P.E. Jones, A new famiły of foundry alloys. Foundry Trade J., 148 (1980) 114-131.

[4] P.P. Lee, T. Savaskan, E. Laufer, Wear resistance and microstructure of Zn–Al–Si and Zn–Al–Cu alloys, Wear 117 (1987) 79–89.

[5] L. Jian, E.E. Laufer, J. Masounave, Wear in Zn–Al–Si alloys, Wear 165 (1993) 51–56.

[6] B.K. Prasad, A.K. Patwardhan, A.H. Yegneswaran, Dry sliding wear characteristics of some zinc–aluminium alloys: a comparative study with a conventional bearing bronze at a slow speed, Wear 199 (1996) 142–151.

[7] Z. Górny, J. Sobczak, Nowoczesne tworzywa odlewnicze na bazie metali nieżelaznych, Wyd. Za-pis, Kraków 2005.

[8] B.K. Prasad, Influence of heat treatment on the physical, mechanical and tribological properties of a zinc-based alloy, Z. Metallkd. 87 (1996) 226–232.

[9] B.K. Prasad, A.K. Patwardhan, A.H. Yegneswaran, Influence of heat treatment parameters on the microstructure and properties of some zinc-based alloys, J. Mater. Sci. 31 (1996) 6317–6324.

[10] S. Murphy, T. Savaskan, Comparative wear behaviour of Zn–Al-based alloys in an automotive engine application, Wear 98 (1984) 151–161.

[11] Z. Wendorff, Metaloznawstwo; WNT, Warszawa 1972.

[12] N. Mykura, S. Murphy, YH. Zhu, Volume change in ternary Zn–Al–Cu alloy. Mater Res Soc Symp Proc 1984;21:841–6.

[13] Y.H. Zhu, S. To, X.M. Liu, W.B. Lee, Microstructural changes inside the lamellar structures of alloy ZA27, Materials Characterization 57 (2006) 326–332

[14] M. Tokarski, Metaloznawstwo metali i stopów nieżelaznych w zarysie; Wyd. Śląsk, 1985.

[15] YH. Zhu, Decomposition reactions in a quench-aged eutectoid alloy AlZn75Cu3Si2. J Mater Sci Technol 6 (1990) 125–31.

[16] T. Savaskan, A. Aydıner, Effects of silicon content on the mechanical and tribological properties of monotectoid-based zinc–aluminium–silicon alloys, Wear 257 (2004) 377–388