

Shaping surface wear properties of the ZnAl-based MMCS

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The presented work deals with shaping of the properties of the high-aluminium Zn-(24-27) wt% Al (ZnAl25) alloy by reinforcing it with Al_3Ti particles. On the basis of the performed examinations it was stated that the binary tetragonal $DO_{22} Al_3Ti$ aluminide transforms within the ZnAl25 melt to a ternary cubic $L1_2 Ti(Al,Zn)_3$ aluminide [22]. The bigger $Ti(Al,Zn)_3$ particles act as structure reinforcement while the smaller as centres of nucleation [13]. The presence of the reinforcing particles allows to increase hardness by about 20%, while the structure refinement allows to improve plastic properties of the matrix ZnAl25 alloy.

Keywords: Zn-Al based alloys, wear, $Ti(Al,Zn)_3$ trialuminide, in-situ composite, heterogeneous nucleation

INTRODUCTION

The family of the Zn-Al based alloy with increased Al content is now a popular group of the cast alloys according to their good mechanical and physical properties. These are so called high-aluminum zinc-base alloys, designated ZA27 [1], Z284 [2] and ZA35 (or ZA 305) [3]. The work upon the high-aluminium zinc alloys with improved strength properties started in Germany in 1940s - 1950s [4 - 5] and allowed to introduce them into practice during the 1960s [1], [3], [6 - 8]. However, the sand castings of the high aluminum Zn alloys solidify naturally with a coarse dendritic structure of decreased plastic properties. Additionally, their strength decreases significantly in temperatures above 100 °C. [1]. Thus, the investigations are mainly focused on refining the structure and on improving strength and wear properties at elevated temperatures.

The refinement of structure aims at refining the α' primary dendrites of solid solution of zinc in aluminum, which are the main structure constituent of the binary alloys Zn-(24-40) wt%Al [9] - which alloys, in turn, are matrix for the Z284, ZA27 or ZA35 industrial alloys. The works performed on grain refinement of the high aluminium Zn alloys with the Al-Ti and Al-Ti-B master alloys stated, that the refining process causes significant increase of the grains population and changes shape of the dendrites α' from a branched - linear to a semi-globular one [3, 10 - 11]. An increase by about 20% of elongation of ZA27 alloy doped with the Al-Ti-B master alloy was obtained with practically unchanged tensile strength and impact resistance [3]. Similar results were obtained using new alternative master alloys, built on the Zn-Ti system [12-13] - Fig. 1.

The Zn-Ti master alloys exhibit very good solubility in liquid Zn-Al alloys in temperature beginning from about 450°C and have higher density than that of modified alloys. These features simplify introduction of master alloy into the melt and allow to avoid detrimental melt overheating, which appears when the traditional master alloys Al-Ti or Al-Ti-B are used. Additionally, using the Zn-Ti master alloys, instead of the Al-Ti ones, allows to reduce the costs of energy and material.

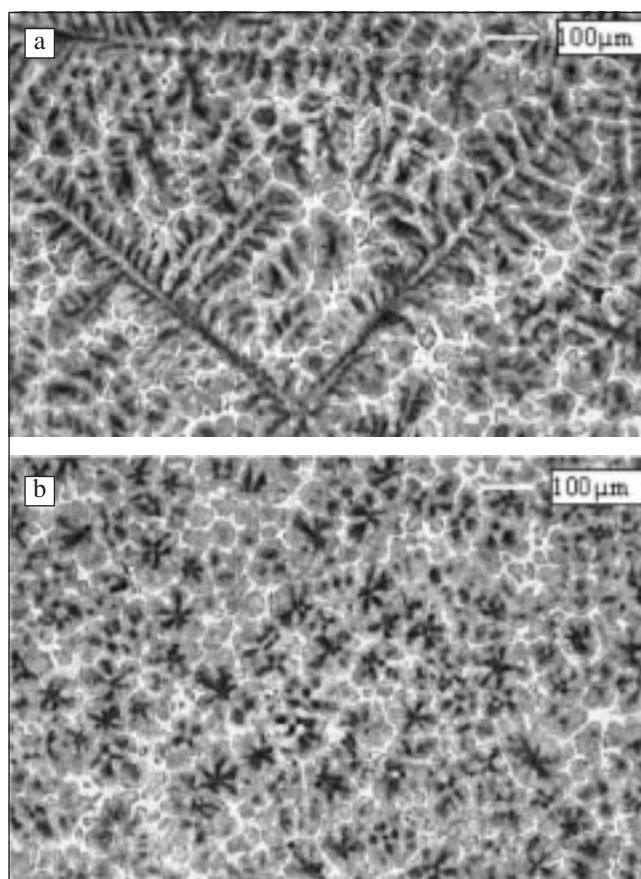


Fig. 1 – LM picture of the initial binary ZnAl25 sand-cast alloy. (a) Unrefined structure. Visible branched dendrites of solid solution of Zn in Al - ZnAlss (darker) and non-equilibrium eutectic (lighter); (b) Refined structure of the same alloy doped with ZnTi4 master alloy. Visible refined, semi-globular dendrites of ZnAlss.

Fig. 1 – Immagine al microscopio ottico della lega binaria iniziale ZnAl25. (a) Struttura non affinata. Dendriti ramificate visibili della soluzione solida di Zn in Al - ZnAlss (più scuro) e non-equilibrio eutettico (più chiaro); (b) La struttura affinata della stessa lega dopata con la lega ZnTi4. Dendrites semi-globulari affinate visibili di ZnAlss.

The second direction of the investigations is focused on improving properties at elevated temperatures. As it was already mentioned above, the high aluminium zinc alloys have insufficient hardness and their strength rapidly drops in temperatures above 100 °C. These disadvantages can be eli-

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mi-nated by addition of reinforcing fibres or particles, like SiC, Al₂O₃ or TiC [14 - 21]. During these examinations Al₃Ti particles were used as the reinforcement and the refiner of the Zn- 25 wt % Al alloy (ZnAl25) and Zn - 25 wt % Al -1 wt % Cu (ZnAl25Cu1) alloy. The obtained changes of structure and properties of the examined alloys were compared with those of the initial Zn-25 wt % Al-2.5wt%Cu initial alloy (ZnAl25Cu2.5).

EXPERIMENTAL

Initial alloys Zn-25wt% Al (ZnAl25), Zn-25wt% Al-2.5wt% Cu (ZnAl25Cu2.5), Zn-25wt% Al-1wt% Cu (ZnAl25Cu1) and Al-12.5wt%Ti (AlTi12) were prepared from electrolytic aluminum (minimum purity 99.96%), electrolytic zinc (99.995%), electrolytic copper (minimum purity 99.95%) and titanium sponge (98-99.8%, from Johnson Matthey Alfa). The Zn-Al and Zn-Al-Cu alloys were melted in an electric resistance furnace, in an alumina crucible of

0.2 liter capacity. The AlTi12 alloy was melted in a Balzers induction furnace with a protective argon atmosphere. The obtained ingot of the AlTi12 master alloy was the source of the Al₃Ti particles. The melts of ZnAl25 and ZnAl25Cu1 alloys were superheated to about 600°C and the AlTi12 master alloy was added to give an overall titanium content of 2wt% (ZnAl25Ti2) and 1.5 wt% (ZnAl25Cu1Ti1.5). Five minutes after the AlTi12 addition, the bath was stirred for 2 minutes with an alumina rod, and the alloys were cast into a dried sand mould with vertical cylindrical cavity Ø 30 x 80 mm. From the middle part of castings samples about 25 mm high were cut for structural and hardness studies. After grinding (on SiC grades 200, 400, 600, 800 and 1000) they were polished using 6 µm and 1 µm diamond pastes and finally using a suspension of 0.5 µm alumina in water-ethanol. Light-microscopy observations were performed on samples etched in a diluted aqua regia, using Leica DM IRM microscope. Scanning electron microscopy (SEM) investigations were performed on unetched samples using Philips XL30 microscope equipped with an energy dispersive X-ray EDX

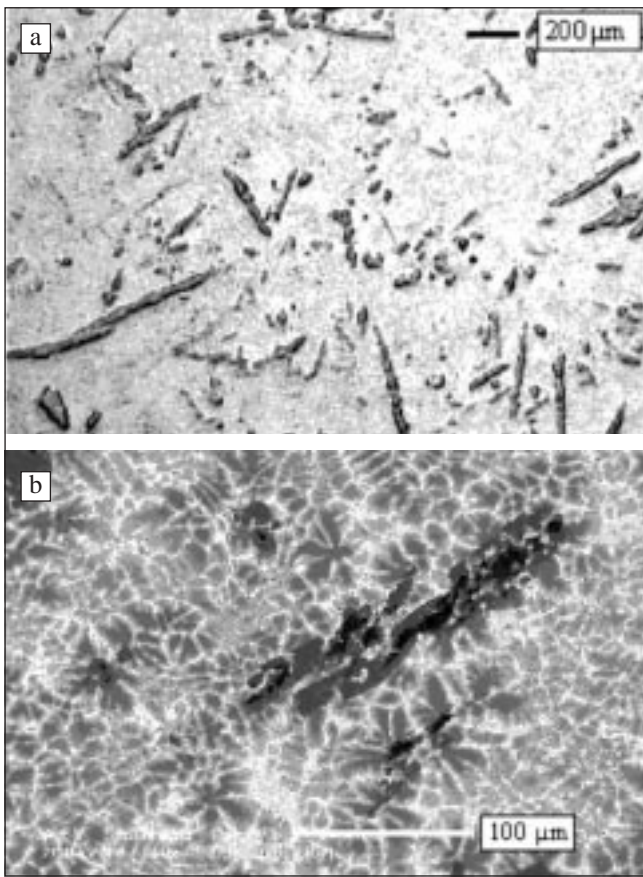


Fig. 2 – (a) LM picture of the ZnAl25Ti2 alloy doped with AlTi12 master alloy. Visible needles of the Al₃Ti base reinforcing particles. (b) SEM picture of the same alloy. Non-uniform in composition Al₃Ti base phase visible in the refined matrix.

Fig. 2 – (a) Immagine al microscopio ottico della lega ZnAl25Ti2 dopata con la lega AlTi12. Visibili gli aghi delle particelle di rinforzo della base Al₃Ti. (b) Immagine al SEM della stessa lega. Fase non uniforme in composizione della base Al₃Ti visibile nella matrice raffinata.

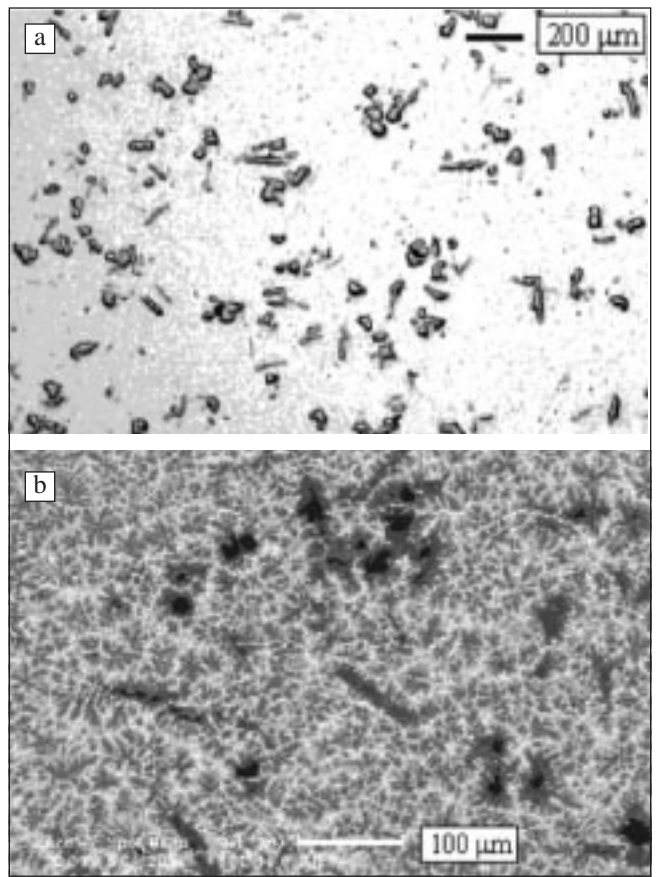


Fig. 3 – (a) LM picture of the ZnAl25Cu1Ti1.5 alloy doped with AlTi12 master alloy. Visible mixed needle-blocky reinforcing particles of the Al₃Ti base phase. (b) SEM picture of the same alloy. Non-uniform in composition Al₃Ti base phase visible in the refined matrix.

Fig. 3 – (a) Immagine al microscopio ottico della lega ZnAl25Cu1Ti1.5 dopata con la lega AlTi12. Visibili particelle di rinforzo miste aghiformi-a blocchi della fase a base Al₃Ti. (b) Immagine al SEM della stessa lega. Fase non uniforme in composizione della base Al₃Ti visibile nella matrice affinata.

Alloy Points:	ZnAl25Ti2					ZnAl25Cu1Ti1.5				
	1	2	3	4	5	1	2	3	4	5
Al	64.60	47.58	59.37	29.70	2.77	64.66	49.53	63.04	46.13	8.10
Ti	33.69	30.35	0.25	0.15	0.0	33.55	29.69	0.43	0.17	0.0
Zn	1.65	22.07	40.38	70.15	97.14	1.74	20.70	36.19	53.16	89.94
Cu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.34	0.53	1.89

Table 1 – Composition (in %) in the points shown in Fig. 4 (a) and (b).

Tabella 1 – Composizione (%) nei punti indicati in Fig. 4 (a) e (b).

spec-trometer Link-Isis. Wear-resistance investigations were performed using pin-on-disc method (T01M device, made in Poland) and using samples 8 mm in diameter and 24 mm in length cut from the Ø 30 x 80 mm castings. The dry sliding wear test was performed against a rotating steel disc of 110 mm in diameter and 10 mm in height, and hardness of 50 HRC. The test was carried out at load giving 0.8 MPa pressure and at sliding speed of about 0.7 m/s, for a total sliding distance of 10 km. Ambient temperature during the test was about 21-22°C, at air humidity of 50-55%. The coefficient of friction was measured during these tests.

RESULTS AND DISCUSSION

Structure

The structure of the examined ZnAl25-Cu alloy after total or partial replacing Cu with Ti addition is shown, accordingly, in Figs 2 and 3.

Hardness and Wear

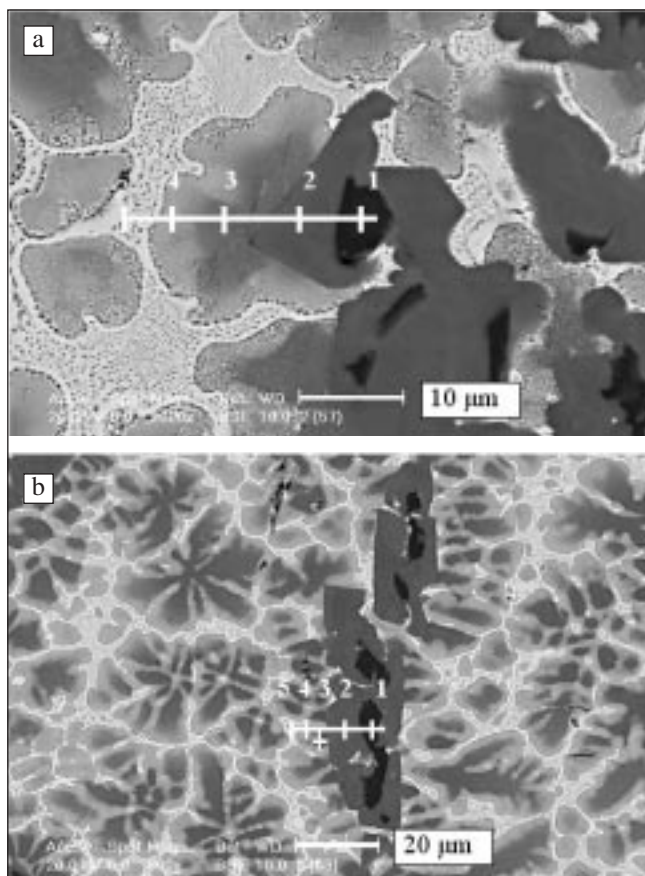


Fig. 4 – Examples of composition of the reinforcing particles and surrounded matrix. A particle taken (a) from the ZnAl25Ti2 alloy (Fig. 2). (b) from the ZnAl25Cu1Ti1.5 alloy (Fig. 3).

Fig. 4 – Esempi di composizione delle particelle rinforzanti e della matrice circondata. Una particella (a) dalla lega ZnAl25Ti2 (Fig. 2). (b) dalla lega ZnAl25Cu1Ti1.5 (Fig. 3).

ZnAl25Cu2.5		ZnAl25Ti2		ZnAl25Cu1Ti1.5	
HRB	µ	HRB	µ	HRB	µ
75	0.28	95	0.33	92	0.25

Table 2 – Hardness HRB and coefficient of friction m (maximal values during the test) of the examined alloys.

Tabella 2 – Durezza HRB e coefficiente di attrito m (valori massimi durante la prova) delle leghe esaminate.

The results obtained during the sliding test of the examined alloys on the T01 M device and measurements of hardness are collected in Table 2. The Ti(Al,Zn)₃ particles present in microstructure of the examined reinforced alloys increase their hardness by about 20% in relation to the initial alloy ZnAl25Cu2.5. At the same time the coefficient of friction obtained in the test conditions remains basically unchanged.

FINAL REMARKS

On the basis of the results obtained in this work the following conclusions can be formulated:

1. Partial or total replacement of Cu with Ti, introduced with the AlTi12 alloy, evolves in situ Ti(Al,Zn)₃ particles in microstructure of the examined alloys. These particles act as the reinforcement of the ZnAl25-based composite.
2. The partial or total replacement of Cu with Ti causes a refinement of the branched dendritic morphology of the alloy matrix, i.e. solid solution of Zn in Al; this change should positively influence the plastic properties of the matrix.
3. The refined ZnAl-matrix reinforced with the Ti(Al,Zn)₃ particles allows to obtain improved hardness of the ZnAl25Ti2 and ZnAl25Cu1Ti1.5 alloys. However, in comparison with the initial ZnAl25Cu2.5 alloy - the ZnAl25Ti2 alloy shows also slightly increased value of its coefficient of friction, while the ZnAl25Cu1Ti1.5 alloy shows a slightly decreased coefficient of friction.

Summing up, the partial replacement of Cu with Ti allows to increase hardness with basically pre-served coefficient of friction of the examined alloys, which is the positive achievement of this replacement.

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— A B S T R A C T —

**MODELLAZIONE DELLE PROPRIETÀ DI USURA SUPERFICIALE
DI MMC A BASE DI ZnAl**

*Parole chiave: alluminio e leghe,
usura, proprietà dei materiali, caratterizzazione*

Il presente lavoro si occupa della modellazione delle proprietà della lega ad alto tenore di alluminio Zn-(24-27) % in peso Al (ZnAl25) mediante rinforzo con particelle di Al₃Ti.

Sulla base delle analisi effettuate è stato dimostrato che l'aluminide tetragonale binario DO₂₂Al₃Ti si trasforma nella fusione dello ZnAl25 in un aluminide cubico ternario LI₂Ti(Al,Zn)₃ [22]. Le particelle più grandi di Ti(Al,Zn)₃ agiscono da rinforzo strutturale mentre le più piccole come centri di nucleazione [13]. La presenza delle particelle rinforzanti permette di aumentare la durezza del 20% circa, mentre l'affinamento della struttura permette di migliorare le proprietà plastiche della lega con matrice ZnAl25.