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COMPOSITES THEORY AND PRACTICE

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MICROSTRUCTURE OF AZ91-Ti6Al4V METAL-METAL COMPOSITE IN AS-CAST CONDITIONS AND AFTER HEAT TREATMENT

The results of structure investigations of an experimental magnesium matrix composite reinforced with Ti6Al4V particles in as-cast conditions and after heat treatment are presented. The commercial AZ91 magnesium alloy was used as the matrix alloy. The experimental composite was reinforced with 30 wt.% Ti6Al4V alloy spherical particles. The investigated material was obtained by the stir-casting method. The microstructure of the fabricated composites was characterized by uniform distribution of the titanium particles within the magnesium matrix. The phase composition of the composite was typical for the used component. New phases were not revealed by XRD techniques. Solution annealing at 693 K for 24 h and 48 h (with water quenching), followed by ageing at 423 K for 16 h was carried out. After ageing discontinuous precipitation process of the γ phase (typical for AZ91 magnesium alloy) was observed. The applied heat treatment processes did not bring about changes in the chemical composition between the used components.

Keywords: **metal-metal composite, AZ91 magnesium alloy, Ti6Al4V particles, heat treatment, microstructure**

MIKROSTRUKTURA KOMPOZYTU TYPU METAL-METAL AZ91-Ti6Al4V W STANIE PIERWOTNYM ORAZ PO OBRÓBCE CIEPLNEJ

Przedstawiono wyniki badań struktury kompozytów na osnowie magnezowej z cząstkami Ti6Al4V w stanie pierwotnym oraz po obróbce cieplej. Na osnowę kompozytu wytypowano komercyjny stop magnezu AZ91. Doświadczalny kompozyt umacniany był 30% wag. sferoidalnych cząstek Ti6Al4V. Badany materiał został wytworzony metodą odlewniczą. Mikrostruktura wytworzonego kompozytu charakteryzowała się jednorodnym rozmieszczeniem cząstek tytanowych wewnątrz magnezowej osnowy. Skład fazowy kompozytu był typowy dla użytych komponentów. Nie ujawniono metodami XRD występowania tych faz. Przeprowadzono ujednorodnianie w temperaturze 693 K przez 24 i 48 h (z chłodzeniem w wodzie) ze starzeniem w temperaturze 423 K przez 16 h. Po starzeniu obserwowano proces nieciągłego wydzielania fazy γ (typowego dla stopu magnezu AZ91). Użyte procesy obróbki cieplnej nie wywołały zmian w składzie chemicznym pomiędzy zastosowanymi komponentami.

Słowa kluczowe: **kompozyt metal-matal, stop magnezu AZ91, cząstki Ti6Al4V, obróbka cieplna, mikrostruktura**

INTRODUCTION

Low density and the unique combination of properties are the main advantages of magnesium and its alloys, especially attractive in the automotive and aerospace industries where the aim is to minimize the weight of individual components. Commercially cast magnesium alloys for automotive applications are mainly AZ (Mg-Al-Zn) and AM (Mg-Al-Mn) series alloys, wherein aluminum is the major alloying element. Because of their high specific strength and good castability, these series have been used for some structural components of automobiles and aircraft. The most widely used is the AZ91 alloy [1, 2]. Mg-Al type alloys are characterized variable solubility of their elements in a solid state with temperature. Therefore, these alloys are heat treated to modify their properties. Conventional heat treatment (T6 conditions) comprises solution annealing (for a minimum of 24 h), followed by aging [3, 4].

Magnesium matrix composites is a constantly developing group of materials. The reinforcing phases (in form of powder, fibers or whiskers) are introduced into the magnesium matrix mostly by conventional methods such as stir casting, squeeze casting and powder metallurgy [5]. Hard ceramic particulates like SiC, TiC, Al_2O_3 or TiB_2 are the most widely studied reinforcements for magnesium matrix composites. These phases are useful reinforcements mainly to improve the stiffness and hardness, damping capacity or tribological properties of magnesium matrix composites. Nevertheless, brittle ceramic reinforcement causes a strong decrease in ductility [5-7]. For that reason, different reinforcements for MMCs are also sought. In comparision to ceramic particles, metallic reinforcements have better wettability with molten matrix alloys, greater ductility as well as higher thermal and mechanical compatibility with the metallic matrix [8-12]. Cu, Ni and Ti particulates have been used as reinforcement in magnesium matrix composites because of their high melting points and very low solubility in magnesium. Of particular note are Ti particulates because titanium and its alloys are characterized by a high Young's modulus, hardness and sufficient elongation compared to magnesium alloys [12]. Recently, many studies on magnesium-titanium based composites have been conducted, most of which are based on the production of these materials by powder metallurgy techniques [13-20]. It was reported [13] that an addition of 5.6 wt.% Ti particulate to pure Mg improved both the strength and ductility of the final material. Additionally, compared to conventional ceramics used as reinforcements of magnesium composites, the wettability of titanium by molten magnesium was very good [13].

The paper is focused on a new magnesium alloy matrix composite reinforced with $Ti6Al4V_p$ particles fabricated by the stir-casting method. The main objective of the study is to present the as-cast microstructure of the obtained composite and investigate its stability during standard heat treatment for matrix alloys.

EXPERIMENTAL PROCEDURES

The commercial AZ91 magnesium alloy fabricated with the nominal composition given in Table 1 was chosen as the matrix alloy in this study. Ti6Al4V alloy powder in the form of spherical particles (Fig. 1) with the chemical composition listed in Table 2 was chosen as the second component for the metal-metal composite fabrication. The fraction of the particles used was 325 mesh.

The experimental composite was obtained by means of a simple and non-expensive casting method. 30 wt.% $Ti6Al4V_p$ particles were introduced to the mechanical mixing of the molten magnesium alloy under a protective atmosphere. The prepared composite suspension was gravity cast into a metal mould. The fabrication process parameters, such as mixing and casting temperatures, time and rate of suspension stirring, mould temperature, etc, were chosen experimentally. Solution annealing was carried out at 693 K for 24 h (according to standard heat treatment for AZ91 matrix alloy) and followed by water quenching for 48 h (for comparison). The next steps of heat treatment included ageing at 423 K for 16 h, which corresponds to T6 conditions for magnesium alloys.

In order to determine the microstructure, light and scanning electron microscopy techniques were used in this study. A standard metallographic technique was used for sample preparation followed by etching in a 1% solution of HNO_3 in C_2H_5OH in order to reveal the microstructure. The volume fraction of $Ti6Al4V_p$ particles in the fabricated composite was verified by a standard metallographic technique on images from non etched samples using the Image-J program. The phase composition of the fabricated composite before and after heat treatment was analyzed by X-ray diffraction (XRD) using a Brucker D8 Advance diffractometer. $Cu_{K\alpha}$ X-ray radiation was used. The obtained X-ray patterns were normalized for comparison. The reflexes from particular phases were identified according to ICDD PDF cards.

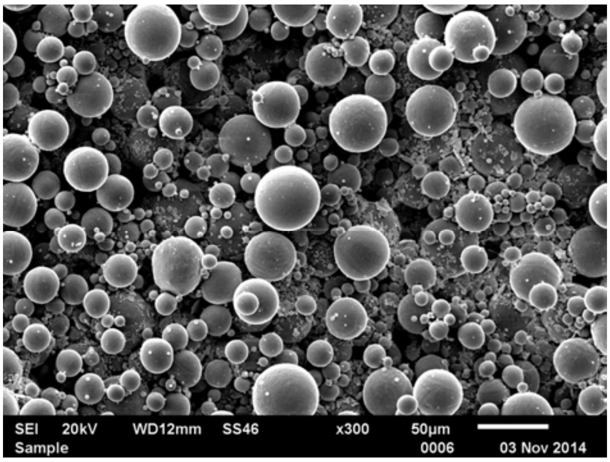

Fig. 1. Micrograph of used Ti6Al4V particles; SEM

Rys. 1. Mikrofotografia użytych cząstek Ti6Al4V; SEM

TABLE 1. **Chemical composition of AZ91 according to ASTM B93-94**

TABELA 1. **Skład chemiczny stopu AZ91 zgodnie z ASTM B93-94**

Chemical composition [wt.%]*							
Alloy	Al	Zn	Mn	Si	Fe	Cu	Ni
AZ91	8.5÷ 9.5	0.45÷ 0.9	0.17÷ 0.4	max 0.05	max 0.005	max 0.03	max 0.002
*Mg rest							

TABLE 2. **Chemical composition of Ti6Al4V particles according to ASTM B-348, grade 23, B214**

TABELA 2. **Skład chemiczny cząstek Ti6Al4V zgodnie z ASTM B-348, grade 23, B214**

Chemical composition [wt.%]*						
Al	V	C	N	O	Fe	Others each
5.5÷6.7	3.5÷4.5	max 0.08	max 0.03	max 0.13	max 0.25	max 0.513
*Ti rest						

RESULTS AND DISCUSSION

Figure 2 shows a typical as-cast microstructure of the fabricated metal-metal composite. The presented composite is characterized primarily by uniform distribution of the $Ti6Al4V_p$ particles within the matrix. The real (verified) volume fraction of $Ti6Al4V_p$ particles in the magnesium alloy matrix was equal to 30 wt.%, which corresponds to the assigned volume fraction, demonstrating the precision of the manufacturing process of the designed composite. Neither particle clusters nor any consequences of floating or sedimentation of the reinforcing phase, frequently occurring in gravity cast composites are observed. Such a uniform distribution of $Ti6Al4V_p$ particles has been possible owing to the good wettability of the titanium particles by the molten matrix alloy and the easy creation of a bond between the metal-metal components. The microstructure observations did not reveal new structural constitutions which can be created due to potential reactions between the components. The matrix has a dendritic structure with a heavy segregation of alloying elements, typical for cast magnesium alloys. The main structural constitutions, e.g. α-Mg solid solution (depleted with alloying elements in comparison to phase diagram) and an α + γ partially divorced eutectic are clearly visible. In commercial AZ91 magnesium alloys, an Al_8Mn_5-type intermetallic phase is also present due to the manganese addition to the alloy. The observed phase composition of the composite was confirmed by X-ray diffraction (Fig. 3a). The X-ray pattern presented in Figure 3 for the composite in as-cast conditions disclosed the presence of reflexes from mainly Mg, the γ phase and $Ti_α$.

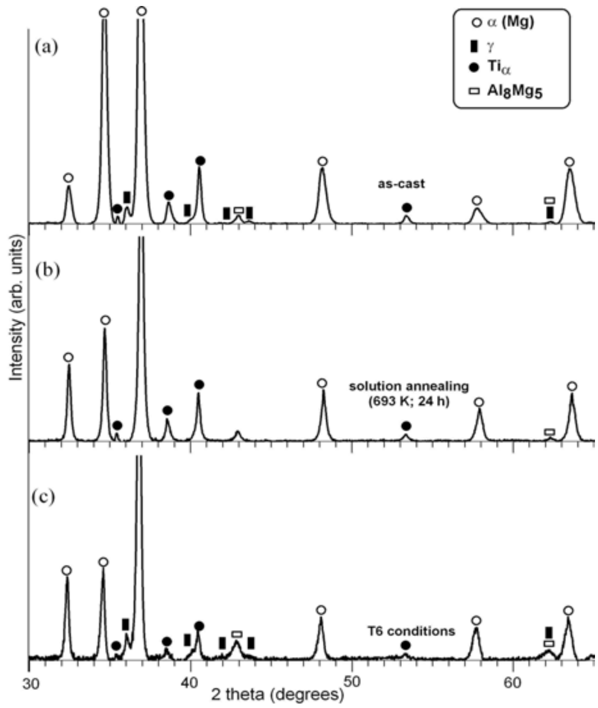

Fig. 3. X-ray diffractions of AZ91-$Ti6Al4V_p$ composite as-cast condition (a) and after solution annealing at 693 K for 24 h (b) and after supersaturated solid solution ageing at 423 K for 16 h (T6 condition) (c)

Rys. 3. Rentgenogramy kompozytu AZ91-$Ti6Al4V_p$ o strukturze pierwotnej (a) oraz po wyżarzaniu ujednorodniającym w 693 K przez 24 h (b) oraz po starzeniu w 423 K przez 16 h (warunki T6) (c)

a)

b)

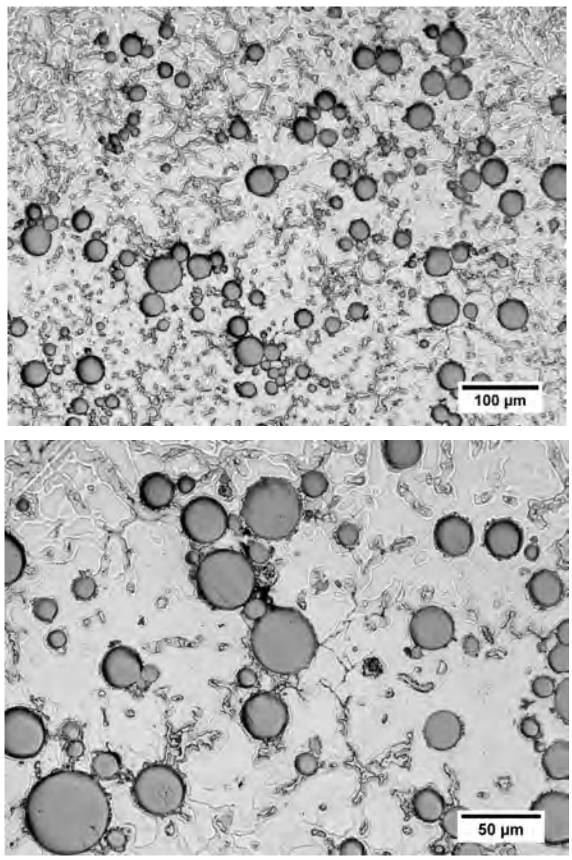

Fig. 2. Microstructure of as-cast AZ91-$Ti6Al4V_p$ composite

Rys. 2. Mikrostruktura pierwotna kompozytu AZ91-$Ti6Al4V_p$

Solution annealing at 693 K for 24 h caused total dissolution of the α + γ eutectic and homogenized the aluminum (and zinc) throughout the matrix. The microstructure of the AZ91-$Ti6Al4V_p$ composite obtained after solution annealing characterized by relatively large grains of the supersaturated solid solution is shown in Figure 4. The dissolution of the eutectic and disappearance of reflexes from the γ phase is clearly visible in Figure 3b. Solution annealing was also carried out in order to check the microstructure stability. It should be noted that the creation of new phases (as products of potential reactions between components, especially Al-Ti - type) were not revealed. Analogically, after solution annealing at 693 K for 48 h, no new phases were observed either. Figure 4 shows a comparison of diffraction patterns obtained from the composite after annealing for 24 and 48 h. The most important range of 2 theta degree was selected in order for the comparison to be more noticeable.

For composites in standard T6 conditions (for AZ91 magnesium alloy), new intermetallic phases were not observed either. The XRD patterns after ageing of the supersatured solid solution at 423 K for 16 h are presented in Figures 3c and 5. Figure 6 shows a typical microstructure of the fabricated metal-metal composite after ageing of the supersaturated solid solution at 423 K for 16 h (T6 conditions). The presented microstructure is characterized by the presence of fine, plate-like, discontinuous γ precipitates. For the AZ91 alloy, this type of precipitates is dominant at a relatively low ageing temperature [4]. Discontinuous precipitation is the cellular growth of alternating plates of the secondary γ phase and near-equilibrium α phase at the high angle boundaries. This heterogeneous reaction leads to the formation of a lamellar structure behind a moving grain boundary.

a)

b)

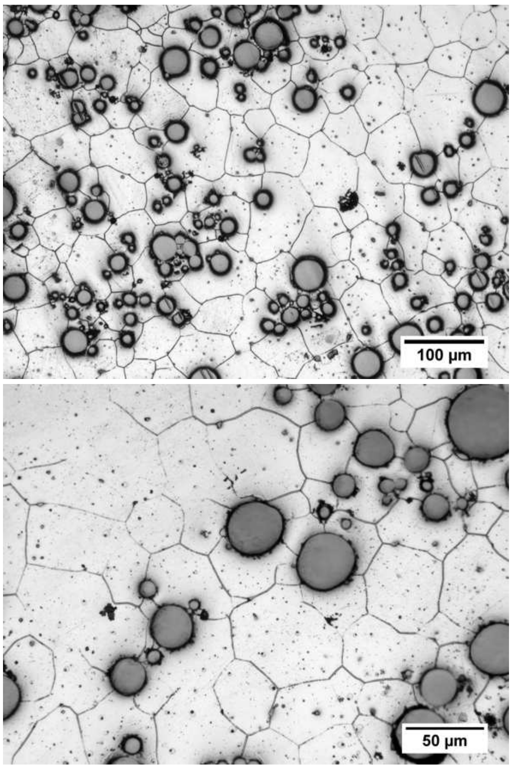

Fig. 4. Microstructure of AZ91-Ti6Al4V_p composite after solution annealing at 693 K for 24 h

Rys. 4. Mikrostruktura kompozytu AZ91-Ti6Al4V_p po wygrzewaniu ujednorodniającym w 693 K przez 24 h

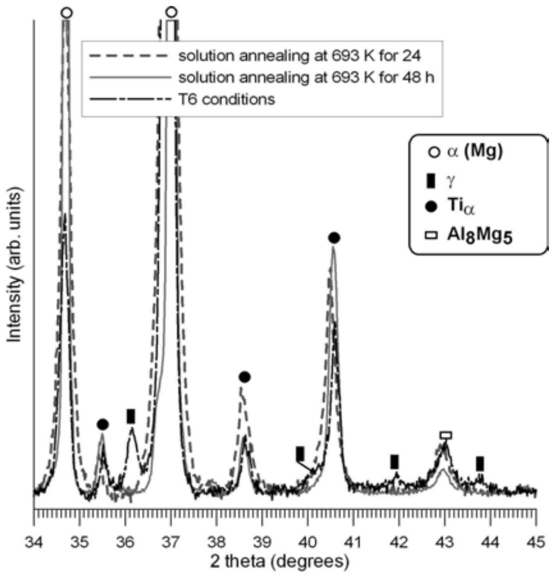

Fig. 5. X-ray diffractions of AZ91-Ti6Al4V_p composite after solution annealing at 693 K for 24 and 48 h and after ageing of supersaturated solid solution at 423 K for 16 h (T6 condition)

Rys. 5. Rentgenogramy kompozytu AZ91-Ti6Al4V_p o strukturze pierwotnej oraz po wyżarzaniu ujednorodniającym w 693 K przez 24 i 48 h oraz po starzeniu w 423 K przez 16 h (warunki T6)

a)

b)

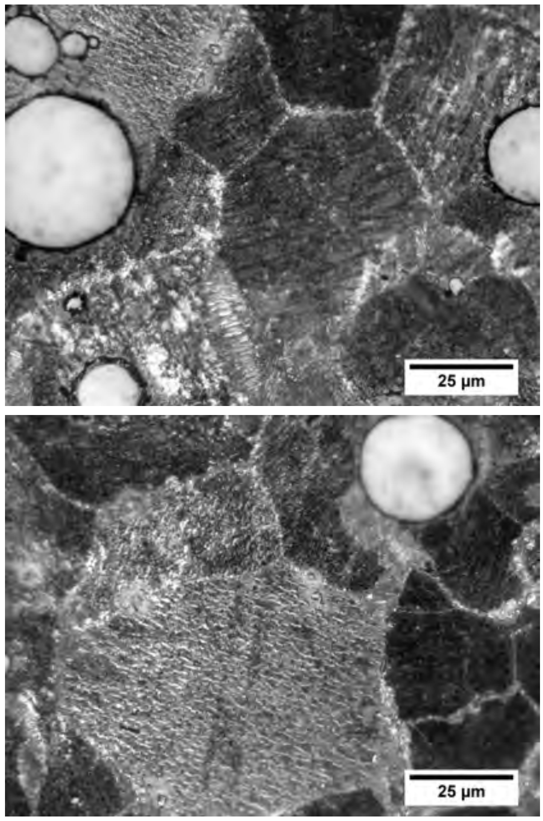

Fig. 6. Microstructure of AZ91-Ti6Al4V_p composite after ageing supersaturated solid solution at 423 K for 16 h (T6 condition)

Rys. 6. Mikrostruktura kompozytu AZ91-Ti6Al4V_p po starzeniu w 423 K przez 16 h (warunki T6)

SUMMARY

The fabricated cast AZ91 magnesium matrix composites with Ti6Al4V particles are characterized by a uniform arrangement of particles within the matrix. An easy fabrication process and a uniform component distribution was possible owing to the good wettability of the particles by the molten matrix and the easy creation of bonds between the two metal components. According to the presented results of the investigation, no new phases (created due to reaction between components) were observed in the as-cast conditions or after standard heat treatment of the composites.

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