POLITECHNIKA ŚLĄSKA
WYDZIAŁ INŻYNIERII MATERIAŁOWEJ

Rozprawa doktorska

mgr inż. Adam Gryc

Procesy wydzieleniowe w stopach Mg-Bi oraz Mg-Bi-X (X = Zn, Mn, Ca)

Promotor:
dr hab. inż. Andrzej KIEŁBUS, prof. PŚ

Katowice, wrzesień 2024 r.

ABSTRACT

In the thesis, an attempt was made to determine the influence of chemical composition and heat treatment parameters on the precipitation processes in Mg-Bi and Mg-Bi-X alloys (X = Zn, Mn, Ca). Tackling of this research problem was motivated by the industry's demand for new magnesium alloys for elevated temperatures application, which do not contain expensive and hardly-available rare earth elements. Mg-Bi alloys may be a potential alternative to these alloys, due to their susceptibility to precipitation hardening. However, the current state of knowledge on their precipitation hardening is limited to only a few scientific publications. The results obtained in this doctoral dissertation allowed the verification, systematization and partial supplementation of information on the influence of alloying elements on the microstructure and properties of Mg-Bi alloys and the precipitation processes occurring during their age hardening.

The experimental part of the thesis included the selection of the chemical composition of the research materials basing on literature data and thermodynamical analysis using the CALPHAD method, fabrication of selected alloys from the Mg-Bi system by means of gravity sand casting technology, characterization of their microstructure and properties in the as-cast state, selection of heat treatment parameters using the dilatometric methods, as well as qualitative and quantitative metallography. The main part of this thesis was the characterization of precipitation processes in Mg-Bi alloys by means of scanning and scanning-transmission electron microscopy, X-ray diffraction and X-ray microanalysis.

Based on the conducted research, the following precipitation sequence for binary Mg-Bi was proposed:

α-Mg → fine precipitates with a diameter of several nm (coherent) → type II polyhedral precipitates of Mg_3Bi_2 phase (coherent) and type I fine, cuboid-shaped precipitates of Mg_3Bi_2 (incoherent or semi-coherent) → type I rod-shaped or plate-like precipitates of Mg_3Bi_2 phase (incoherent)

The influence of alloying elements on the precipitation processes occurring in Mg-Bi and Mg-Bi-X alloys (X = Zn, Mn, Ca) was also determined. Zn promotes the formation of type II polyhedral precipitates of Mg_3Bi_2. However, it causes a decrease of the thermodynamic stability of Mg_3Bi_2 phase, leading to their faster dissolution and promotes discontinuous precipitation of Mg_3Bi_2 phase at grain boundaries. The addition of calcium causes the formation of massive precipitates of Mg_3Bi_2 phase. They nucleate on fine particles of Mg_2Bi_2Ca phase, and with the increasing ageing time, their discontinuous precipitation occurs. This contributes to a significant decrease in the number density of fine continuous precipitates of Mg_3Bi_2 phase. Manganese promotes the nucleation of type I cuboid-shaped precipitates of Mg_3Bi_2 phase, characterized by high thermodynamic stability.

The increase of the mechanical properties of Mg-Bi alloys depends on the size and morphology of Mg_3Bi_2 phase precipitates. At the peak-aged condition, fine coherent type II polyhedral, type I cuboid-shaped and few type I rod-shaped or plate-like precipitates of Mg_3Bi_2 phase are formed in the microstructure of Mg-6Bi, Mg-6Bi-0,5Mn and Mg-6Bi-0,5Zn alloys. In Mg-6Bi-0,5Ca alloy, a negligible precipitation strengthening effect was observed. The reason was a small amount of precipitates formed during ageing, resulting from the discontinuous precipitation of the Mg_3Bi_2 phase.