TENSILE AND COMPRESSIVE CREEP OF MAGNESIUM-ALUMINUM-CALCIUM BASED ALLOYS

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Abstract

In this paper, both tensile and compressive creep properties of the newly developed Mg-Al-Ca-based ACX alloys are reported to be significantly better than those of AE42 alloy. The tensile creep behavior of ACX alloys in this study obeys a power-law type of constitutive equation. The stress and temperature dependencies of the secondary creep rate of ACX alloys were also studied. The results suggest that the improved creep resistance in ACX alloys can be primarily attributed to the thermal stability and the interfacial coherency of the $(Mg,Al)_2Ca$ phase in the microstructure of the alloys.

Introduction

Magnesium, one of the most promising lightweight materials, has made significant inroads in automotive interior and other room- or near-room-temperature applications in the last decade. The most visible magnesium applications in North America have been instrument panel beams, transfer cases, valve/cam covers, steering components and various housings and brackets [1]. The poor creep resistance and high costs of commercial magnesium alloys have prevented magnesium applications in major powertrain components such as engine blocks and automatic transmission cases, where the operating temperatures can be as high as 250°C and 175°C, respectively. Recent efforts to develop creep-resistant alloys for such applications have resulted in a number of experimental alloys. The majority of these experimental alloys are based on Mg-Al-Ca system, which was reviewed in a recent TMS paper [1].

General Motors Research & Development Center (GM R&D) has been working on magnesium alloy development for the past four years. A new series of Mg-Al-Ca alloys containing small additions of strontium and/or silicon (designated as ACX alloys) was developed at GM R&D. The results of this work will be published at the 2001 Society of Automotive Engineers (SAE) World Congress in Detroit [2, 3]. The new ACX alloys offer excellent creep resistance (under both tensile and compressive stresses) and low cost that meet the materials requirements for automotive powertrain applications. This paper reviews the creep mechanisms in pure magnesium and Mg-Al based alloys. Tensile and compressive (bolt-load retention) creep behavior of the ACX alloys is presented along with an in-depth analysis of the creep mechanisms of the Mg-Al-Ca alloys.

Creep in Magnesium Alloys

The plastic deformation of metals and alloys depends on the temperature and dislocation structure existing in the materials. The flow stress (σ) of a pure metal consists of two basic components as proposed by Taylor [4]:

$$\sigma = \sigma^* + \sigma_E \qquad (1)$$

where

σ^* is often called ***thermal component*** and involves thermal activation; and

σ_E, ***work-hardening component***, is dislocation-structure-dependent and is associated with the interaction of stress fields of the dislocations in the material.

The fact that the flow stress contains a component that responds to thermal activation implies that plastic deformation can occur while both the temperature and stress are maintained constant. The time-dependent deformation under these conditions (constant stress and temperature) is known as ***creep***. Creep deformation is possible at all temperatures above absolute zero [4]. However, since it depends on thermal activation, the higher the temperature, the more significant the creep phenomenon becomes.

It is generally agreed [5-14] that the steady-state secondary creep rate (d) of magnesium and Mg-Al based alloys is described by a power-law equation in the stress (σ) and temperature (T) ranges of interest to automotive applications (σ = 20-100 MPa; and T = 100-250°C):

$$d = A\,\sigma^n \exp(-Q/RT) \qquad (2)$$

where A is a material-related constant, R is the gas constant, Q is the ***apparent activation energy*** for creep and n is known as the ***stress exponent***. Based on Equation (2), the slope of the log d vs. log σ plot at a given temperature is the stress exponent n, and an Arrhenius plot (ln d vs. $1/T$) at a specific stress level will yield the apparent activation energy (Q) value. The n and Q parameters can be used to infer the dominant creep mechanisms for a material in specific ranges of stress and temperature.

Shi and Northwood [5] studied the creep of pure polycrystalline magnesium in the ranges of σ = 20-50 MPa and T = 150-250°C. The stress exponent (n = 5.86) and the apparent activation energy (Q = 106 kJ/mol) values obtained suggested a creep mechanism