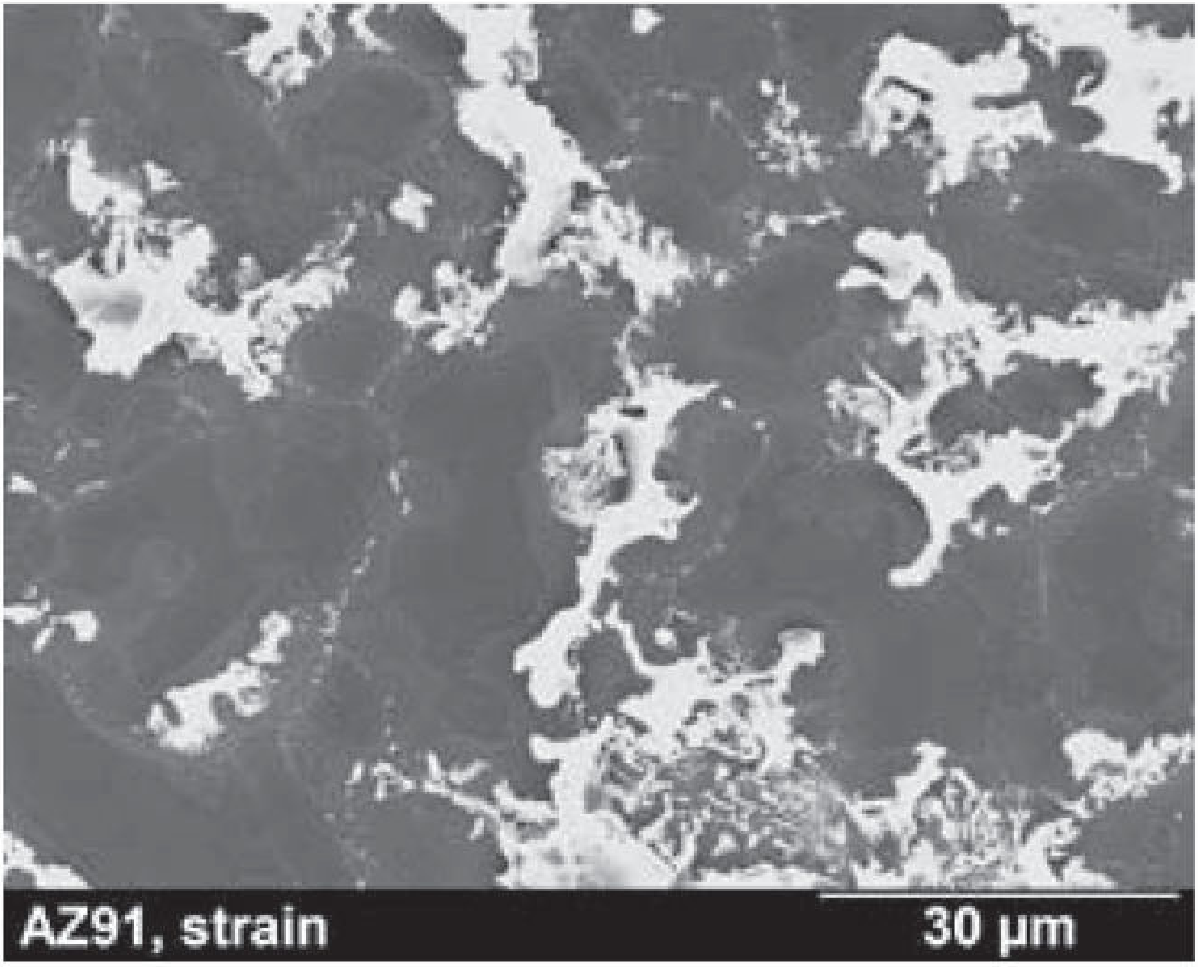
Ping Zhang

Correlation of the Microstructure and Creep Behavior of Die-cast Mg-Al-base Alloys



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Correlation of the Microstructure and Creep Behavior of Die-cast Mg-Al-base Alloys

(Zusammenhang zwischen Mikrostruktur und Kriechverhalten von Mg-Al-basis Druckgußlegierungen)

Der Technischen Fakultät der
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CONTENTS

Chapter 1

Introduction

Magnesium is the lightest of all the commonly used metals, and is particularly attractive for automotive application as well as aircraft [1, 2]. Since the 1930's, Mg-Al alloys have been used in Volkswagen cars, for example the engine block of VW Beetle. The use was given up in 1968 as a result of increased strength requirements [3]. Since a few years Mg alloys have seen a renaissance as light-weight materials for automobiles. This is reflected by the increasing number of research programs and conferences [4, 5, 6, 7] dedicated to Mg and its alloys [8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. Especially, Mg alloys are good for fast production of extended thin-walled parts by pressure die-casting. However, in contrast to steel and many Al-alloys, the conventional Mg-alloys have a relatively low resistance to creep. In cars the Mg-alloys have to withstand elevated temperatures, reaching up to 150°C for the transmission housing of the AUDI A6. Under these conditions the time dependence of the deformation of Mg alloys can no longer be neglected. In the past, therefore a basic research program was started in cooperation with AUDI AG, Ingolstadt, to understand and quantify the time dependent deformation behavior of the new high purity Mg-Al-base alloys at elevated temperatures [18].

So far, good progress has been achieved in this project [18]. The investigations were concentrated on die-cast AZ91 in the as cast state because it is the most frequently used for application. In addition die-cast AS21, AS41, AM60 and AE42 were investigated for comparison. A simple model of plastic deformation with one microstructural parameter, the overall density of dislocations, was applied to the Mg-alloys [19, 20, 21, 22, 18]. The model contains the coupled differential equations for the kinetics of deformation and the evolution of the dislocation structure. It is able to reproduce the essential features of deformation under conditions of creep as well as relaxation for AZ91 and AS21. This shows that the approach chosen in this work is promising.

However, the microstructural basis of the model is still weak. This is true with regard to the dislocation structure as well as the grain and phase structure of the alloys. So far there is very little electron microscopic information of the structure in the micrometer (μm) range (μ-structure). Only in one case a specimen of die-cast AZ91 has been prepared and investigated by transmission electron microscopy [23]. The results are encouraging as they prove that structural observations in the (sub-) μ range are possible. However, these singular observations cannot provide a sound quantitative basis for formulating the laws of microstructural evolution.

Lacking such basis these laws have been formulated by making an educated guess based on knowledge which has been accumulated for other metallic materials, in particular Al- and Fe-base alloys. Therefore it is urgently necessary to check and revise the quantitative assumptions made on dislocation density, the precipitates and their hardening action.

This work was planned to provide such a microstructural basis. The investigations start with the standard alloys AZ91 and are extended to AS21 in the undeformed and deformed state. It becomes clear that as cast AZ91 undergoes structural changes at elevated temperature which lead to deterioration of the creep resistance, and that the microstructural origin of the difference on creep resistance between AZ91 and AS21 is due to the different species in precipitation hardening. Moreover, it also becomes clear that die-cast AZ91 represents a good compromise as a material which is relatively easy to handle (good castability, good corrosion resistance) and has reasonable strength and ductility.

Chapter 2

Experimental Methods

2.1 Experimental Materials

2.1.1 Commercial Mg-alloy Systems

The method of the American Society for Testing and Materials (ASTM) [24] is usually used to name magnesium (and other) alloys. This method is a letter-number system. The first part consists of code letters indicating the two principal alloying elements (listed in order of decreasing alloys content). These code letters are listed as follows:

A:	Aluminum	M:	Manganese	S:	Silicon	B:	Bismuth
N:	Nickel	T:	Tin	C:	Copper	P:	lead
W:	Yttrium	D:	Cadmium	Q:	Silver	Y:	Antimony
E:	Rare earth metals	R:	Chromium	Z:	Zinc	L:	Lithium
K:	Zirconium	H:	Thorium				

The second part consists of the weight percentages of these two elements (rounded off to the nearest whole number and listed in the same order as the code letters). For example, AZ91 is a magnesium alloy containing approximately 9% aluminum and 1% Zinc.

2.1.2 Experimental Materials

The high-purity (hp) die-cast magnesium-aluminum alloys AZ91, AS21, AS41, AM60 and AE42 used in present work were supplied by AUDI company, Ingolstadt. They were produced by pressure die casting. The compositions of these alloys are shown in Table 2.1 [25]. The materials were obtained in the form of plates of 165 mm length, 140 mm width and thicknesses varying in steps from 2.5 to 25 mm, as shown in Fig. 2.1 [26]. The porosity was in the order of 1%.

Alloy	Al	Zn	Mn	Si	Fe	Cu	Ni	Be
AZ91	8.9	0.79	0.21	0.01	0.003	0.001	0.001	0.0007
AS21	2.2	<0.01	0.16	0.98	<0.01	<0.001	<0.001	<0.001
AS41	4.6	0.01	0.44	0.82	0.003	<0.001	0.001	<0.001
AM60	6.1	0.01	0.29	0.01	0.002	0.002	0.001	6ppm
AE42	3.9	0.004	0.37	0.007	0.0003	0.0003	0.0009	9ppm

Table 2.1: Composition of alloys (in wt%).

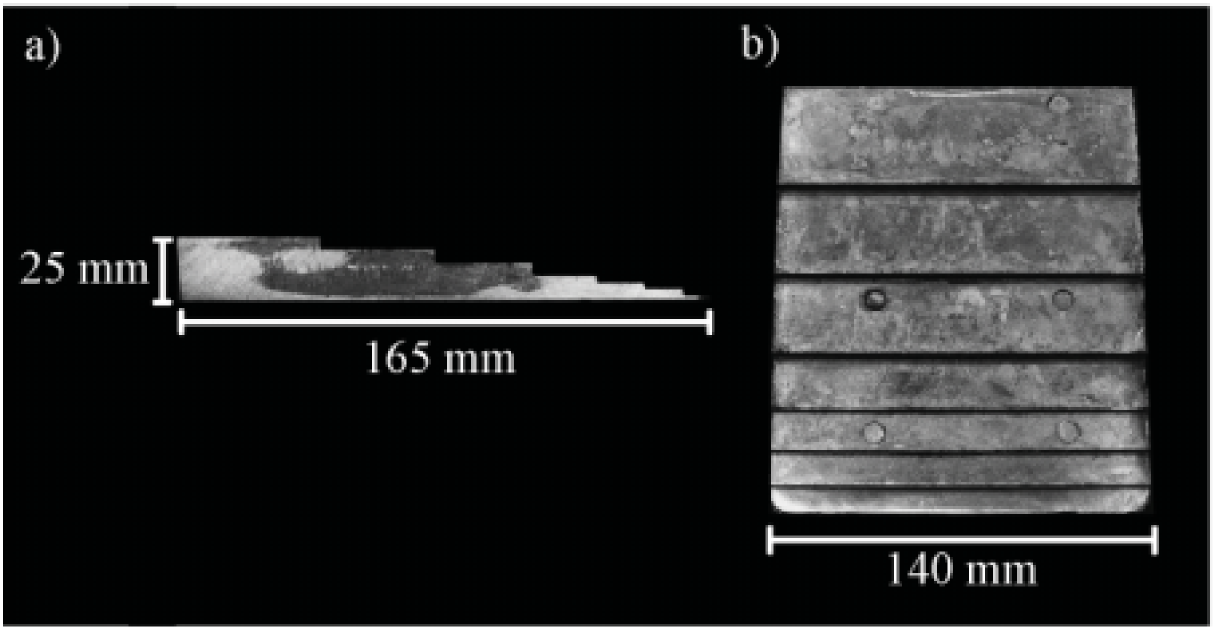

Figure 2.1: The shape of die-cast materials as received.