PROPERTIES OF CAST MAGNESIUM MATRIX COMPOSITES AT ELEVATED TEMPERATURES

K.U. Kainer, F. Moll

Institut für Werkstoffkunde und Werkstofftechnik, Technische Universität Clausthal, Agricolastrasse 6, D-38678 Clausthal-Zellerfeld, Germany

SUMMARY: The alloy AZ91 was used as matrix material for composites reinforced by 10 vol.% of SiC particles. The composites were produced by liquid mixing and squeeze casting. Apart from a few particle clusters the composites showed a uniform and homogenous particle distribution. Particles could be found both at grain boundaries and within the grains, indicating sufficient wetting of the particles by the molten metal. The unreinforced alloy was processed under the same conditions to enable a comparative evaluation of properties and microstructures. Tensile tests and creep tests under constant stress conditions up to 200°C were carried out. It could be observed, that the ultimate tensile strength of the as-cast MMC was increased by the particle reinforcement at 150°C and even at 200°C. A slight improvement of creep resistance due to the particle reinforcement became evident only when creep took place at the lower temperature and stress regime.

KEYWORDS: magnesium matrix, stir-casting, SiC particles, particle reinforcement, properties at elevated temperatures, tensile strength, creep rate

INTRODUCTION

The use of magnesium as a constructional material is limited by its low stiffness, low strength at elevated temperatures, low wear resistance and the high coefficient of thermal expansion. An extensive enhancement of critical properties particularly at higher temperatures can be realised by means of a reinforcing phase such as particles, short fibres or long fibres. Reinforcement of magnesium materials by particles has proved to be advantageous as the production processes enable isotropic composites to be produced economically. The reinforcing effect is less than that for fibre reinforcement but it is possible to achieve a whole range on properties that can be varied by varying the parameters such as matrix alloy, particle shape, size as well as particle volume fraction. Powder metallurgical as well as casting methods can be used to produce particle reinforced magnesium alloys. Both processes enable manufacture of near net shaped parts. In the powder metallurgical route gas atomised powder is mixed with the particles and subsequently consolidated by extrusion, powder forging, etc. to fully dense materials. In the case of casting methods such as stir-casting or compo-casting have proved to be very effective by stirring the reinforcing phase into the molten metal and subsequent processing the composite melt by ingot casting or squeeze casting.

EXPERIMENTAL DETAILS

Fabrication of composites and experimental procerdure

The magnesium alloy AZ91 is a non heat resistant alloy containing ~~9~~% aluminium, ~~1~~% zinc and ~~0~~.2% manganese. Some physical and mechanical properties of the SiC particles used are listed in Table 1.

Table 1: Physical and mechanical properties of SiC particles

	cristall structure	melting-point [°C]	density [g/cm^3]	CTE [10^{-6} K]	Young`s modulus [GPa]	thermal conductivity [W/(mK]
SiC	hexgonal	2300	3,21	5,00	480	59

The preparation of composites was performed by combining both stir-casting and squeeze-casting processes. Therefore preheated particles of 9µm (F400) and 17µm (F600) on average were poured into the vortex obtained from the impeller rotation inside the melt and stirred for several minutes. After the stir process had been completed the composite melt was poured into the die of a squeeze cast press and compressed under high pressure to produce a dense and pore free material. The particle volume fraction was set at 10%. The as cast composites were machined into specimens for tensile and creep testing with diameters of 5mm and 4.5mm and gauge lengths of 25mm and 25.4mm, respectively. The mechanical properties were determined using a PC controlled universal testing machine at a strain rate of 3.3 x $10^{-4}s^{-1}$ at room temperature, 150°C and 200°C. Creep tests were carried out under constant stresses at 35 and 70 MPa and temperatures of 150°C and 200°C. Light microscope and SEM were used for microstructural analysis.

RESULTS AND DISCUSSION

Microstructure of composites

The microstructure of the composites is shown in Fig. 1. The larger reinforcement material revealed a more regular and homogeneous distribution than the smaller particles. The latter tended to form agglomerates and clusters. However, particles could be found both on grain boundaries and within the grains. This is evidence of sufficient wetting of the SiC particles by the liquid metal as has been concluded elsewhere [1, 2]
The intermetallic compound $Mg_{17}Al_{12}$ as well as the eutectic phase were detected frequently around and closely associated with the particles (Fig. 2), which are obviously favoured nucleation sides. There were no extensive interfacial reactions or any degradation of the SiC particles as is obvious from the microstructure. In contrast to other publications [2, 3] massive formation of the intermetallic phase Mg_2Si in the vicinity of SiC particles due to a reaction between magnesium and the silicon released by the ceramic could not be confirmed. Fig. 3 shows an x-ray dot mapping of silicon on a particle and the surrounding matrix. As can be seen the highest concentration of silicon is distinctly restricted to the particle itself and no other silicon enrichment can be observed. This contradictory result may be due to the short period of stirring before squeeze casting.

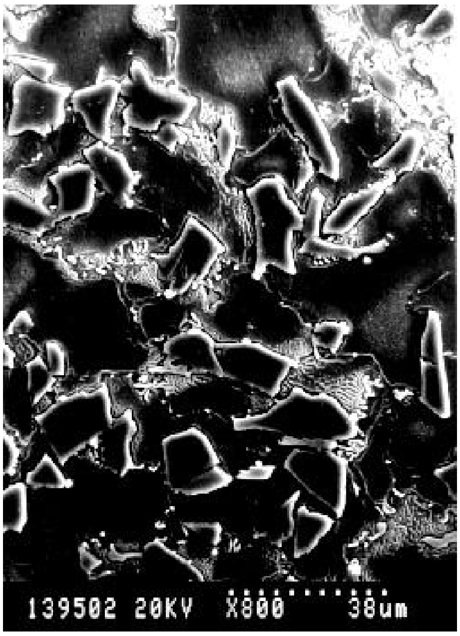
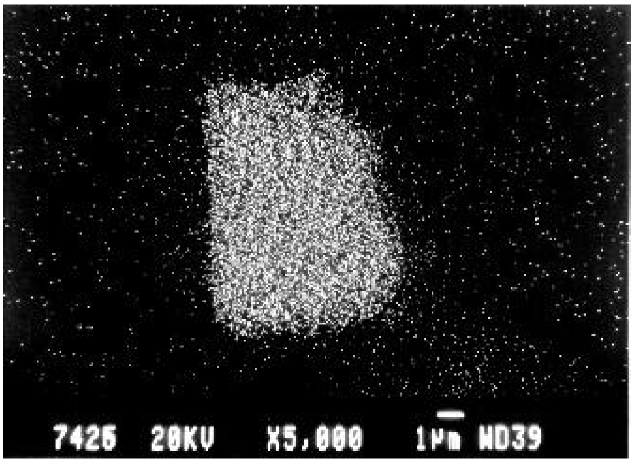


Fig 1: SEM micrograph of an AZ91/SiC$_p$ (F400) composite

Fig. 2: SiC particle enclosed by eutectic and intermetallic compound

However, since fracture surfaces of crept specimen revealed small crystallites on the SiC particles (Fig. 4), it appears that a formation of reaction products at the interface may take place in this composite system [4]. Authors [1, 3], who found similar reactions products covering the particles, concluded them to be of a complex Al-C-O ternary phase accompanied with the formation of Mg_2Si. But, as mentioned previously, the existence of a large amount of Mg_2Si could not be proved in the present composite and observations have now to be focused on the identification of these reaction products.



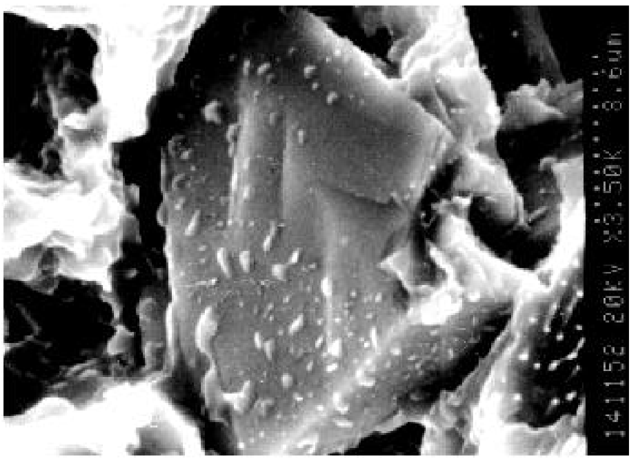


Fig 3: X-ray dot mapping of silicon in an AZ91/SiC$_p$ F400 composite

Fig 4: Reaction products on a particle surface after creep

Mechanical properties and creep behaviour of composites

Strength results obtained from tensile tests at ambient and elevated temperatures are given in Fig. 5. As indicated by the graph the tensile strength of the composites at room temperature is slightly decreased by the particles compared to the unreinforced matrix, whereas strength at higher temperatures could be increased by the reinforcement. The strongest increase in strength at 150°C of about 20 MPa was obtained with the larger particles. The smaller particles led to an increase of tensile strength of about 25 MPa at 200°C.

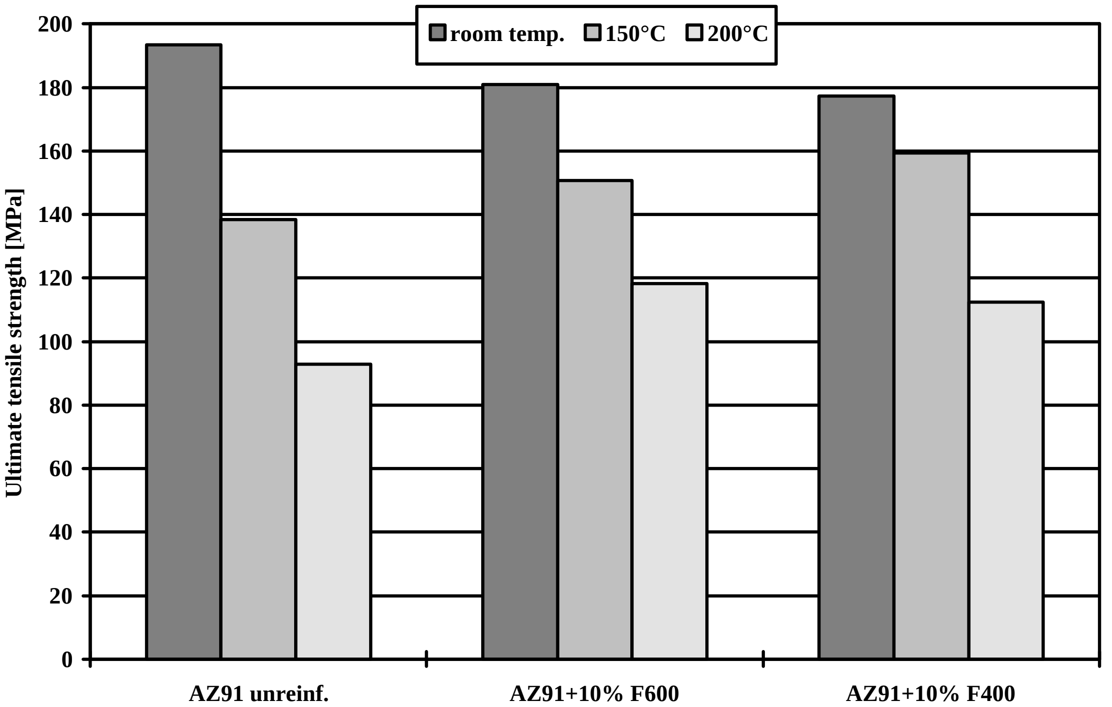


Fig. 5: Tensile properties of AZ91 and AZ91/SiC$_p$ composites in the as cast state at ambient and elevated temperatures

With respect to the creep behaviour of the unreinforced matrix and the composite reinforced by larger particles it could be observed that creep rates were very slightly decreased by the particles or remained almost unchanged at low stress and temperatures, see Fig 6.

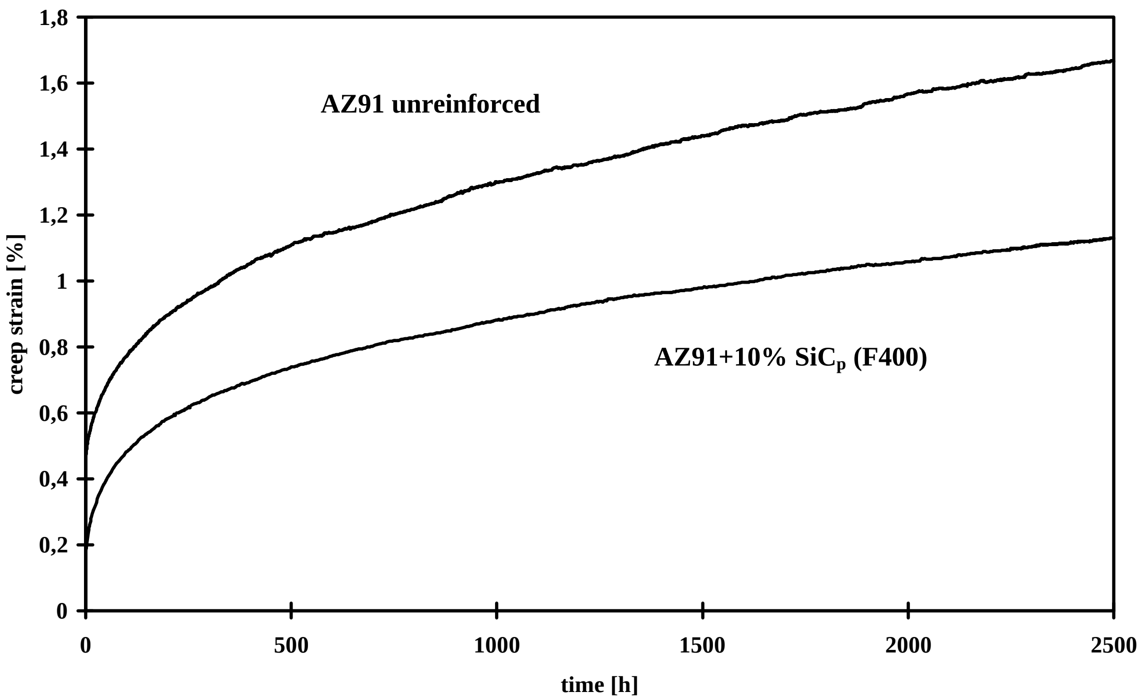


Fig. 6: Creep of unreinforced AZ91 and AZ91/SiC$_p$ (F400) composite at 35 MPa and 150°C

In the case, when a stress of 35 MPa and temperatures of 150°C or 200°C were applied, both unreinforced matrix and composite offered creep rates of an order of 10^{-10} and 10^{-8} s^{-1}, respectively. Creep rates strongly increased with increasing stress. Doubling the stress from 35 MPa to 70 MPa led to creep rates of around 10^{-6} s^{-1} for the composite and 10^{-7} s^{-1} for the unreinforced AZ91. Creep curves of the matrix alloy and the composite at 200°C and 70 MPa are shown in Fig. 7. Distinct ternary creep was obvious only when creep took place at high temperature or high stress. All fracture surfaces after creep showed that the particles became detached from the matrix and it appears that the creep failure took place along the interfaces [4]. Creep tests on the AZ91/SiCp (F600) composite are still in progress and results will be available soon.

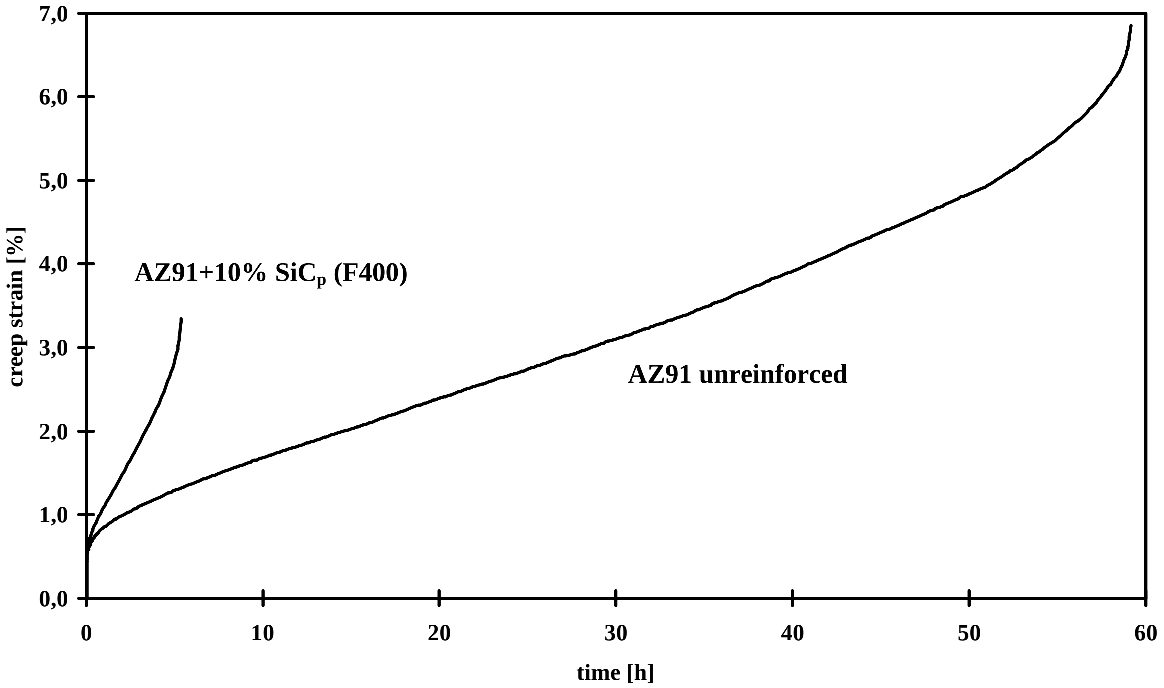


Fig. 6: Creep of unreinforced AZ91 and AZ91/SiC$_p$ (F400) composite at 70 MPa and 200°C

CONCLUSIONS

SiC particle reinforced magnesium matrix composites were prepared by stirring particles into the melt and subsequently squeeze casting. The homogeneity of particle distribution appeared to be dependent on the particle size. Particles of a mean size of 17 µm were evenly distributed, whereas particles with an average size of 9 µm tended to agglomerate. In contrast to other observations no Mg_2Si could be detected within the composite materials. Since the contact time between melt and the ceramic particles was short of the order of several minutes, this result leads to the conclusion that the formation of large Mg_2Si precipitates might be related to a certain incubation time. Large as well as small particle reinforcements produced an improvement in the mechanical properties of AZ91 at elevated temperatures up to 200°C. A very slight improvement in the creep resistance was evident only when creep took place at low temperature and stresses of 35 MPa and 150°C. Since AZ91 is not a creep resistant alloy and the creep properties of the matrix are of great importance for the creep behaviour of a metal matrix composite, insufficient creep strength of the matrix became more significant with increasing temperature and strength.

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