

論 文

# Effect of Alloying Elements on SiC

## Particulate Dispersion Behavior into Molten Magnesium

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熔融 마그네슘中 SiC粒子分散舉動에 미치는 合金元素의 影響

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### 초 록

熔融 마그네슘中 SiC粒子分散舉動에 미치는 合金元素의 影響에 대하여 調査하였다. 마그네슘中 SiC 粒子의 分散을 위한 所要時間은 總時間으로 定義했다. 總時間은 Ce, Mn, Cr, Bi, Pb, Sn 및 Zn을 添加하여도 總時間은 지연되었고 粒塊成의 數는 많이 나타났다.

### 1. Introduction

Magnesium metal matrix composites are promising candidate materials for many aerospace and transport applications because of their high specific strength and stiffness and because they have a near zero coefficient of thermal expansion. Recently, several studies have been carried out on long fiber<sup>(1),(2)</sup> and short fibre reinforced magnesium matrix composites<sup>(3),(4)</sup>. However, these numbers are fewer than those of aluminum matrix composites, moreover the study on particle reinforced magnesium matrix composite is scarcely reported.

In the present work, by using the melt-stirring method which is the most convenient way for manufacturing and takes minimum cost, the fabrication of SiC particle reinforced magnesium matrix composites was attempted. In that case, the effects of alloying elements on SiC particulate dispersion behavior in molten magnesium were investigated with a view to study the uniform-

ity of particulate distribution.

### 2. Experimental Procedure

Magnesium or its alloys of total amount 60g was melted in the MgO crucible (inner diameter 38mm) by an induction furnace under argon atmosphere as shown in Fig. 1. SiC particles wrapped in an aluminum foil were preheated for 420s above the melt held at 973K. Then, SiC particles were added to the melt and melt-stirring was conducted with an alumina rod (diameter 6mm). It was continued until no particles were found at the surface of melt or crucible corner.

Such a time required for the incorporation of SiC particles was defined as an incorporation time, which could be determined within 10% in the relative error. After finishing the stirring, the melt containing reinforcements was poured into metal mold. The distribution of SiC Particles and the behavior of alloying elements were observed by EPMA. In this experiment,  $\alpha$ -SiC particle (4  $\mu$ m in diam-

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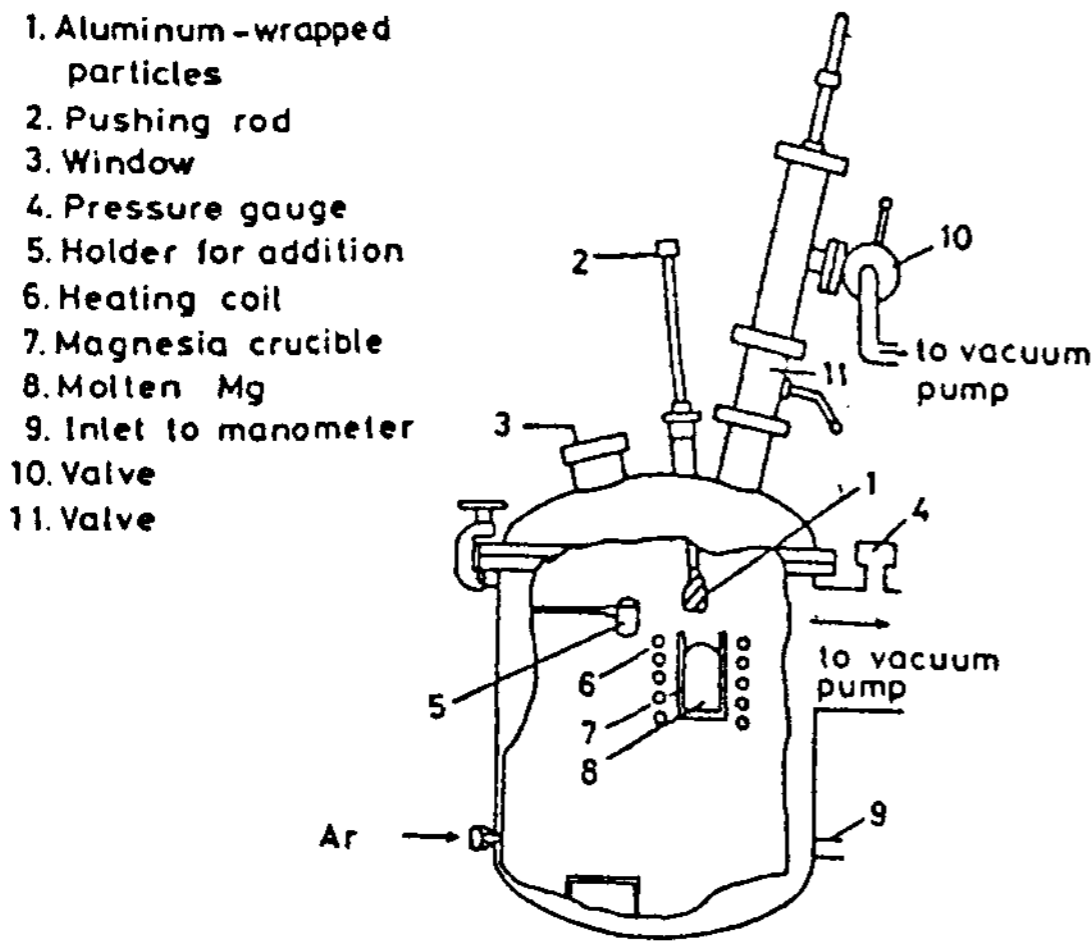


Fig. 1. Schematic view of induction furnace.

eter) was used as reinforcement and the volume fraction of SiC particles was 10%.

### 3. Results

#### 3.1. SiC Particulate dispersion in Pure magnesium

First of all, the incorporation time into molten pure magnesium took about 60s that was remarkably of all, the incorporation time into molten pure magnesium which was rep-

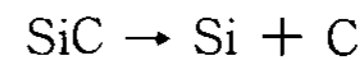
orted by M. Kobash et al<sup>(5)</sup>. EPMA analysis of SiC dispersed in pure magnesium showed the little overlapped parts of (b) magnesium image and (c) silicon image as shown in 2. This suggests that Mg<sub>2</sub>Si seems to be formed in this case. Such formation of magnesium silicide was also confirmed thermodynamically by the Ellingham diagram where the standard free energy of the formation of Mg<sub>2</sub>Si is negative at the experimental temperature(973K).

The reason why incorporation time is shortened for molten pure magnesium is due to the essentially good wettability of SiC particles to magnesium and to the improvement of wettability by reaction of Mg<sub>2</sub>Si formation from magnesium and SiC particles.

#### 3.2 Effect of Ce, Mn and Zr on the incorporation time of SiC

The effects of cerium, manganese and zirconium on the incorporation time were measured. It is clear from Fig. 3 that the incorporation time is not influenced by adding cerium, manganese or zirconium.

By the way, the decomposition of SiC seems to be a dominant factor of the wetting.



Owing to the reaction related above, new

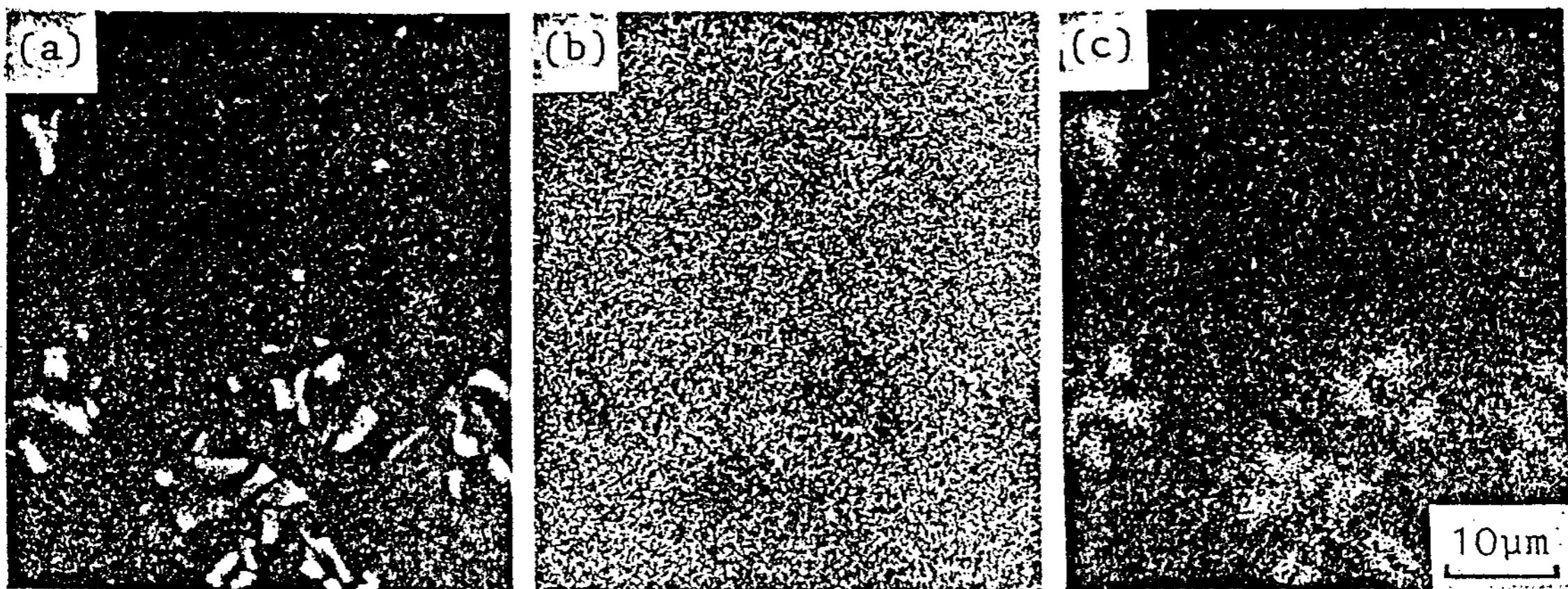


Fig. 2. α-SiC particles dispersed in pure magnesium at 973K.  
(a)COMPO. (b)magnesium image (c)silicon image.

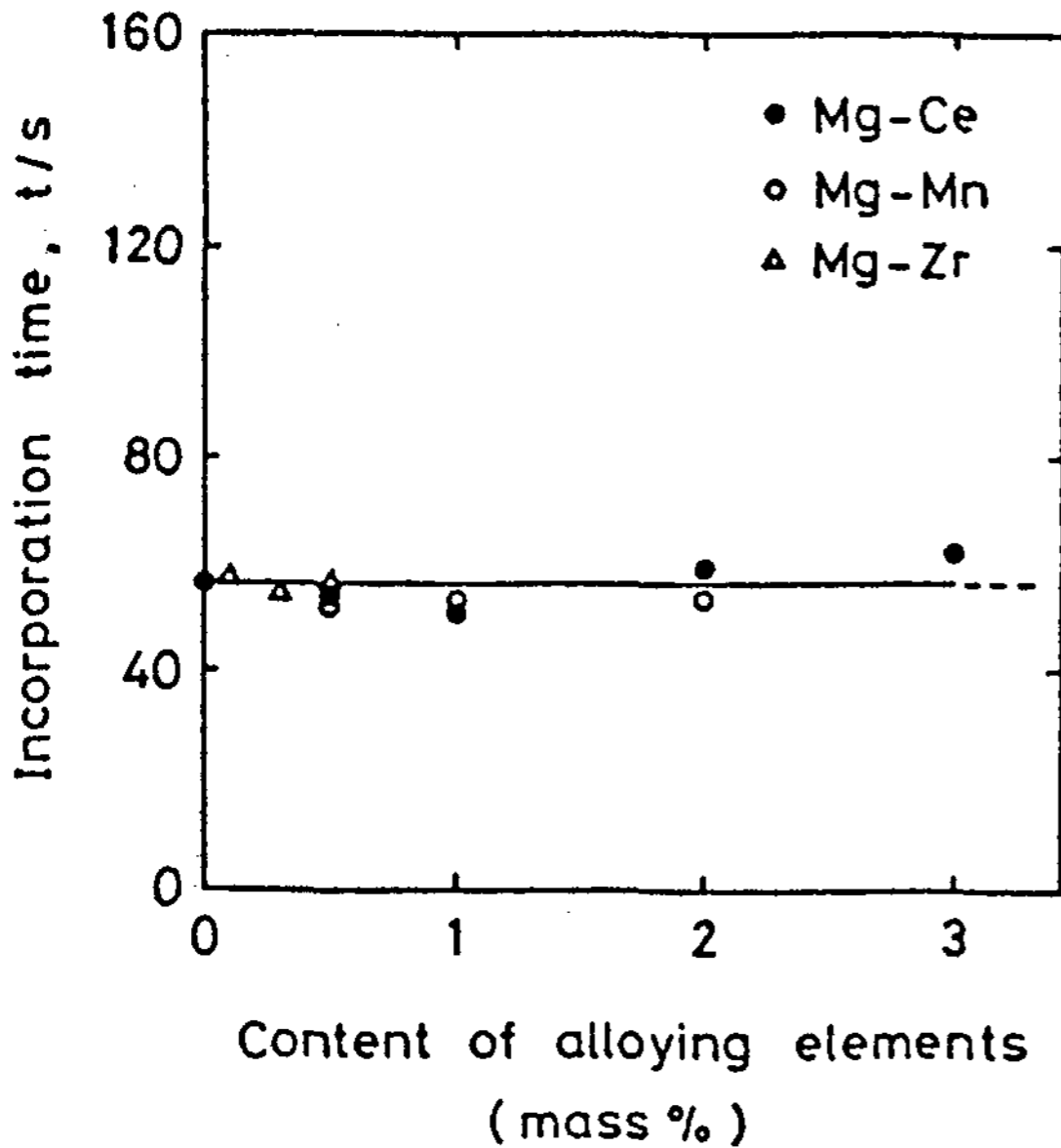


Fig. 3. Effects of cerium, manganese and zirconium on the incorporation time of  $\alpha$ -SiC particles in molten magnesium at 973K.

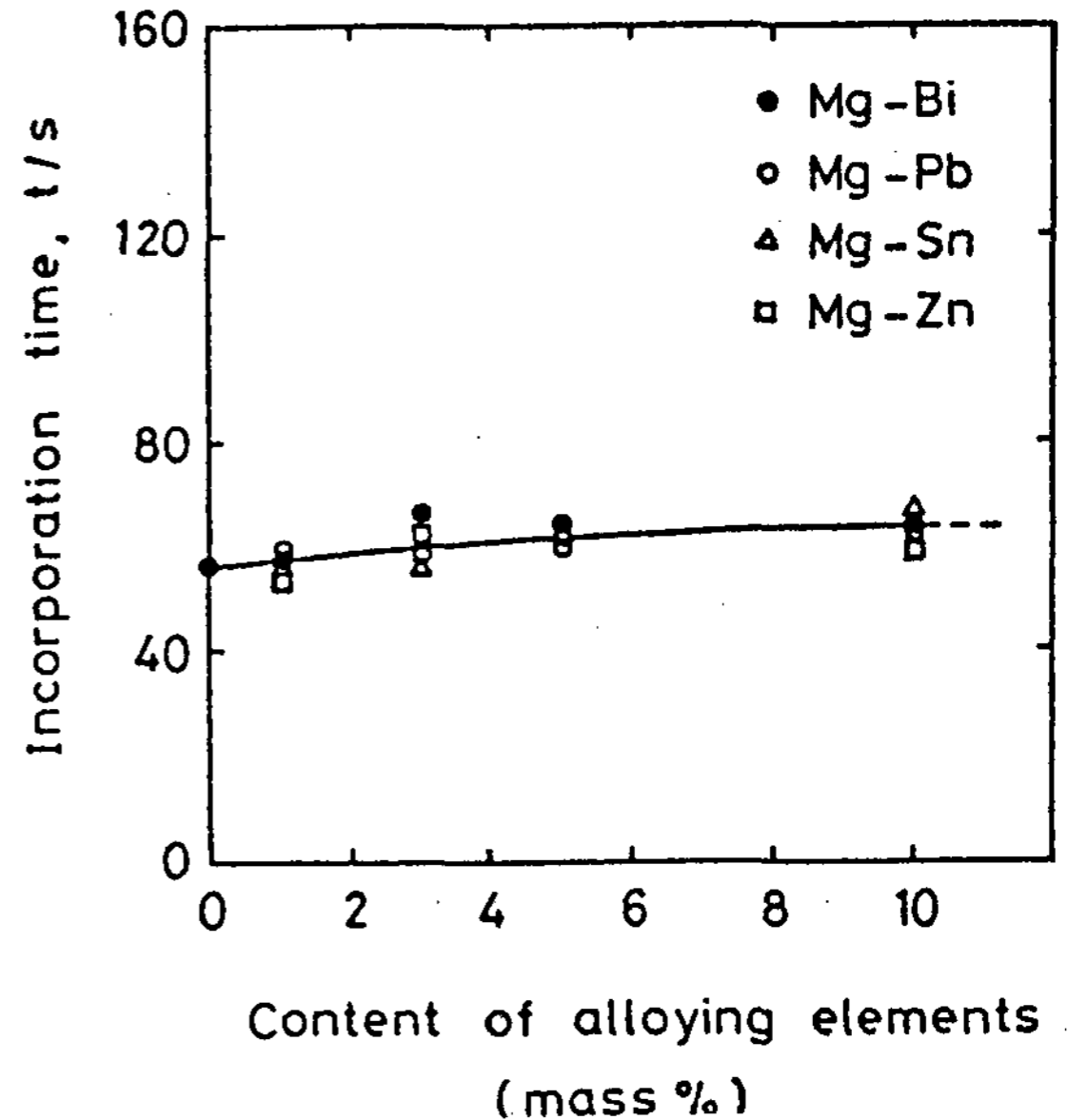


Fig. 4. Effects of bismuth, lead, tin and zinc on the incorporation time of  $\alpha$ -SiC particles in molten magnesium at 973K.

active surface of SiC particle may appear and provide a good wettability. The decomposition reaction of SiC depends on the solubility of silicon in metal. On the other hand, large silicon solubility of excessive decomposition of SiC may rather retard the binding between solid and liquid. Then experimental results were analyzed by using Si-X binary phase diagrams, although such analysis must be carried out by Mg-Si-X ternary phase diagrams that were insufficiently investigated. Because of the small solubility of silicon in manganese or zirconium as in magnesium, manganese or zirconium has no influence on the incorporation time of SiC. On the other hand, the solubility of silicon in cerium could not be confirmed. However, EMPA analysis of Mg-Ce system showed compound having composition as follows: 71.5at.% Mg, 21.9at.%Si and 6.6at.%Ce. Consequently, the formation of magnesium silicide dissolving cerium was ascertained.

The intermetallic compounds i.e., mag-

nesium silicide was also ascertained for Mg-Mn and Mg-Zr systems by EPMA and quantitative analysis.

### 3.3 Effects of Bi, Pb, Sn and Zr on the incorporation time of SiC

The effects of bismuth, lead, tin and zinc on the incorporation time were measured. It is clear from Fig. 4 that the incorporation time is not influenced by adding those elements. This is probably because they do not form their silicides, and have no affinity for SiC and about zero solubilities of silicon in these elements.

However, from the results of EPMA analysis, these added elements formed the intermetallic compound such as Mg-Bi, Mg-Sn and Mg-Pb systems.

Consequently, considering that the intensity of affinity between alloying element and SiC controls the combination and the process of particulate incorporation proceeds by the combination, these elements do not contrib-

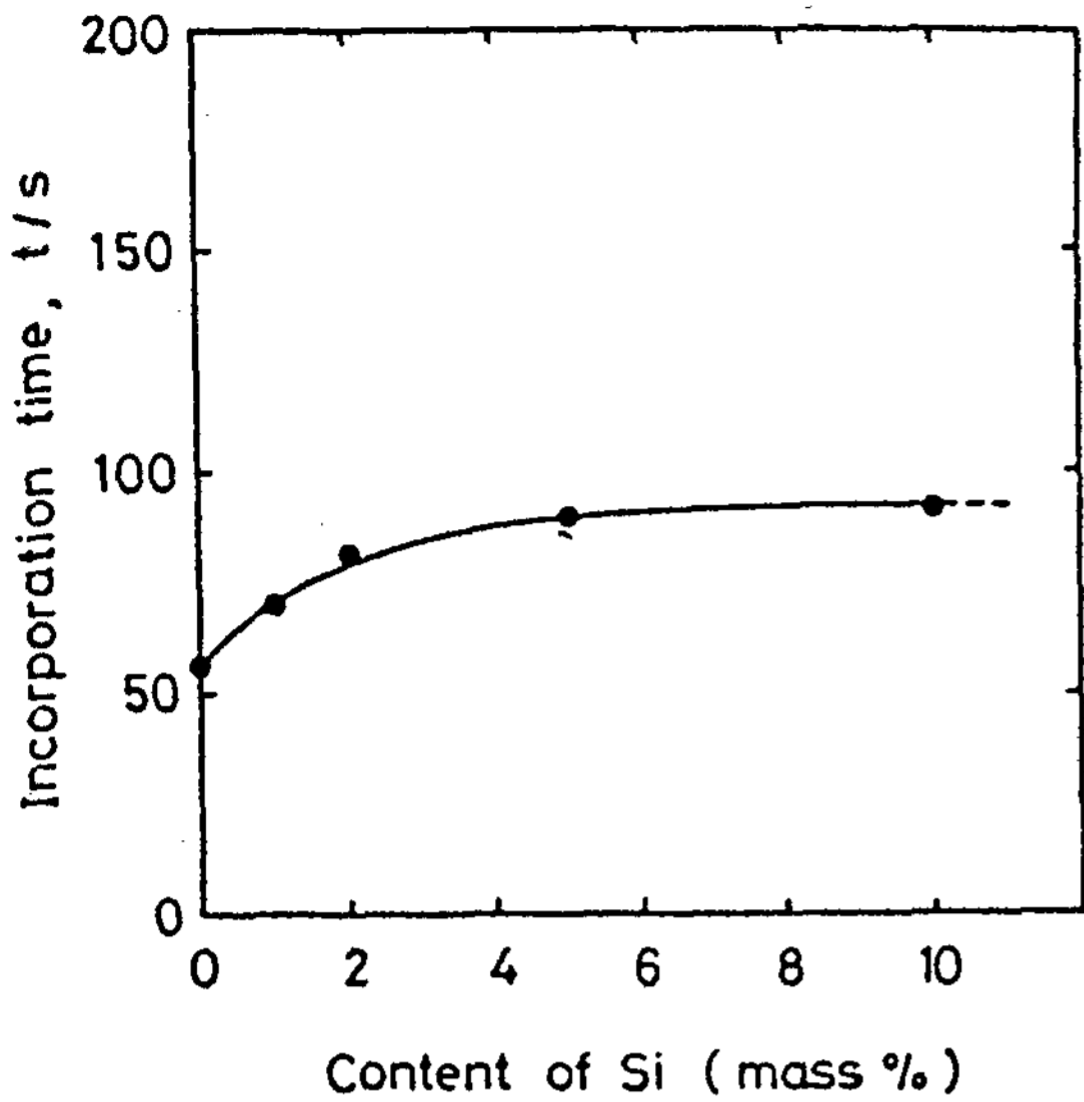


Fig. 5. Effect of silicon on the incorporation time of  $\alpha$ -SiC particles in molten magnesium at 973K.

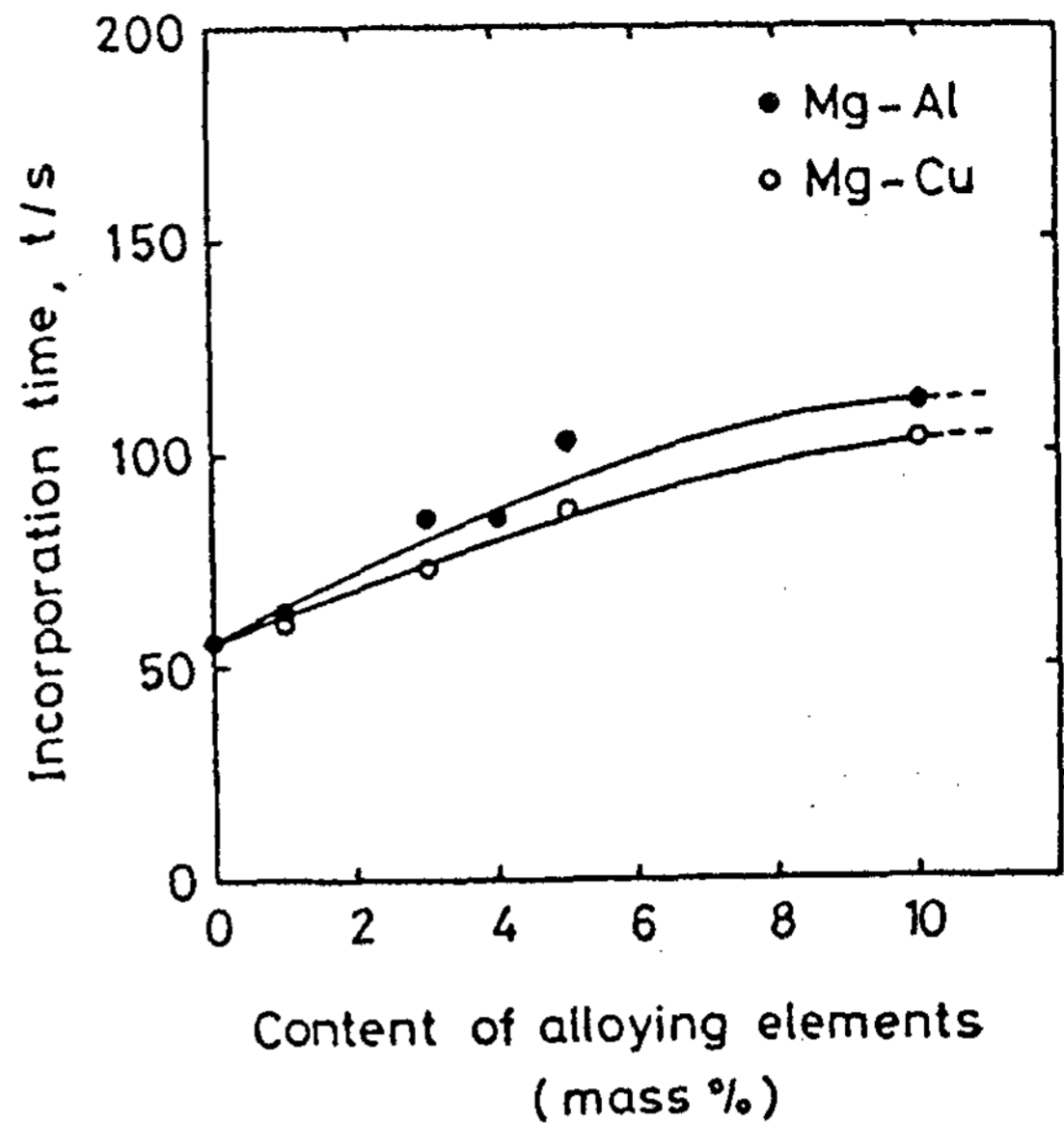


Fig. 6. Effects of aluminum and copper on the incorporation time of  $\alpha$ -SiC particles in molten magnesium at 973K.

ute to the process of particulate incorporation because of a weak affinity for SiC.

### 3.4 Effect of Si on the incorporation time of SiC

The effect of silicon which is a constituent of SiC was also measured. It was clarified that silicon made the incorporation time longer as shown in Fig. 5. This is caused by the retardation of SiC decomposition reaction that is necessary for good wettability.

### 3.5 Effect of Al and Cu on the incorporation time of SiC

The incorporation time was prolonged by adding aluminum or copper as shown in Fig. 6. Aluminum and have a relatively high solubility of silicon in these elements, and also they do not form their silicides.

Therefore, aluminum and copper make the incorporation time longer, preventing the combination between magnesium and silicon.

### 3.6 Effect of Ca on the incorporation time of SiC

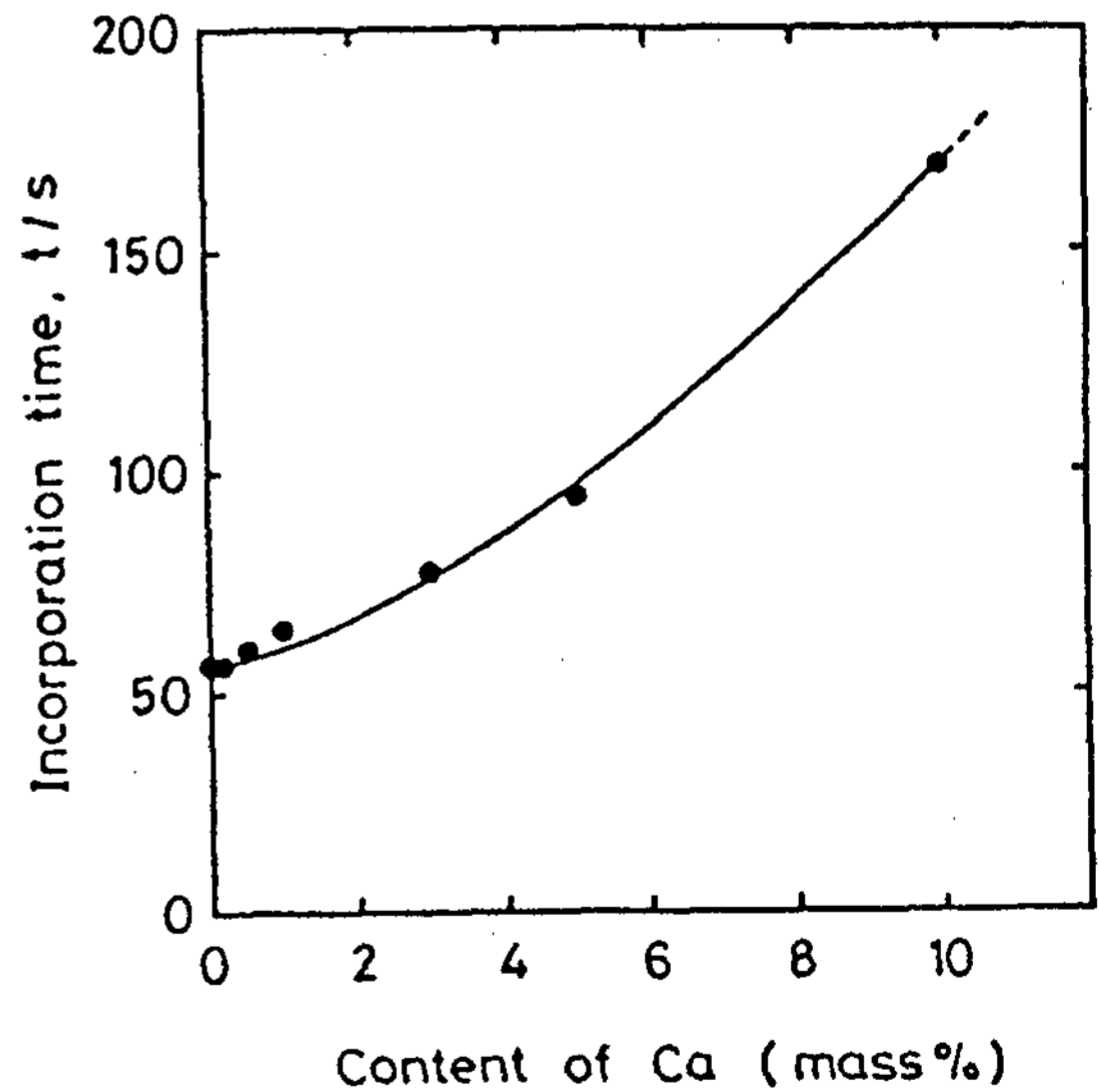


Fig. 7. Effect of calcium on the incorporation time of  $\alpha$ -SiC particles in molten magnesium at 973K.

The effect of calcium on the incorporation time of SiC in molten magnesium is shown in Fig. 7, indicating that the incorporation time



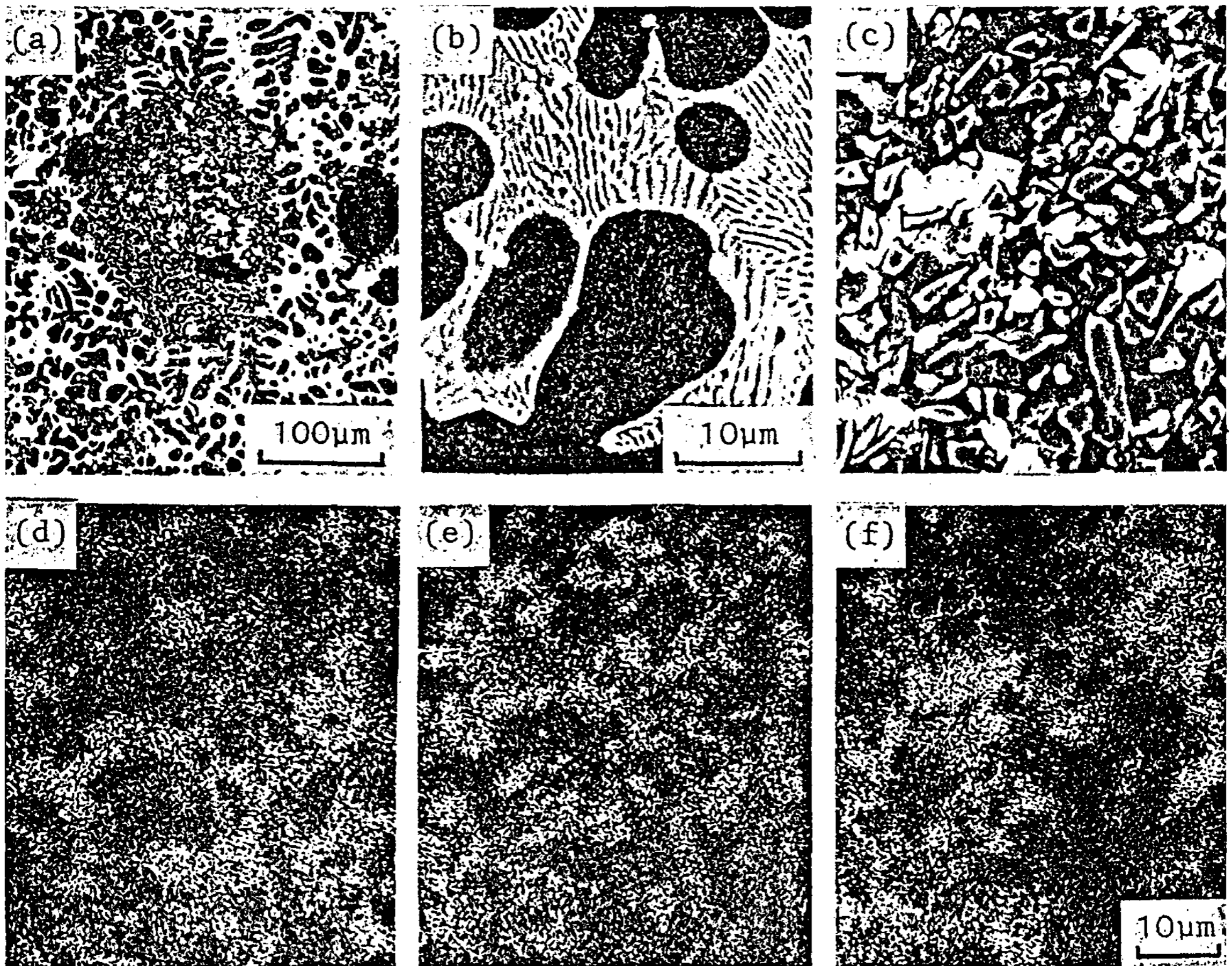


Fig. 8.  $\alpha$ -SiC particles in Mg-5%Ca alloy at 973K.

(a) COMPO. (b) COMPO. (c) magnesium image. (d) silicon image and (f) calcium image

of SiC is getting longer and longer as the addition of calcium increases.

EPMA analysis of SiC/Mg-5%Ca specimen shows the inferior uniformity of particulate distribution and the agglomerate structure of SiC particles as shown in Fig. 8 (a) COMPO. Fig. 8 (b) COMPO shows the typical eutectic structure in the matrix. At the matrix parts in agglomerate structure, the ternary intermetallic compound of 31.0at.%Ca, 32.9at.%Si and 34.8at.%Mg was found.

Therefore, calcium may form calcium silicide at the interface of particles before incorporating, because it has a essentially good wettability and forms silicide easier than

magnesium, resulting in promotion of the combination of particles and formation. of agglomerate. As the density of agglomerated part is lower than that of a particle, the transfer of agglomerate into the melt becomes difficult : namely calcium makes the incorporation time longer.

#### 4. Conclusions

The effects of alloying elements on the incorporation time of  $\alpha$ -SiC into molten magnesium were investigated.

(1) The incorporation time of SiC particles into molten pure magnesium was remarkably

shorter and the condition of particulate distribution was better than those of pure aluminum.

(2) The incorporation time was not influenced by alloying cerium, manganese, zirconium, bismuth, lead, tin or zinc.

(3) The incorporation time was prolonged by alloying aluminum, copper or silicon.

(4) By alloying calcium, the incorporation time was also prolonged and a large number of particulate agglomerate appeared.

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