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IMPACT OF SILICON CARBIDE ON THE MECHANICAL PROPERTIES OF MG-SN-CA_2C ALLOYS PRODUCED BY POWDER METALLURGY

Amr Ali[1], Islam Abdel Sabour[1], M. Salem Ahmed[2], Ahmed I. Ali[3, 4]

[1]Production Technology Department, Faculty of Technology & Education,
Sohag University, Sohag 82524, EGYPT.
[2]Mechanical Technology Department, Faculty of Technology & Education,
Sohag University, Sohag 82524, EGYPT.
[3]Basic Science Department, Faculty of Technology and Education,
Helwan University, Cairo, EGYPT.
[4]Department of Mechanical Engineering, Kyung Hee University,
Suwon, 446-701, REPUBLIC OF KOREA.

ABSTRACT
This study examines the effects of adding silicon carbide (SiC) on the mechanical properties of magnesium-tin (Mg-Sn-CaC) alloys produced via the powder metallurgy process. The objective is to evaluate how these carbides influence the hardness, strength, and overall mechanical performance of the Mg-Sn-CaC alloy. A constant ratio of Mg-Sn (93 wt.%, 2 wt.% Sn, and 5%wt. Ca_2C) were mechanically mixed, with SiC added in varying proportions up to a maximum of 5 wt.%. The phase structure and microstructure were analyzed using X-ray diffraction (XRD) and scanning electron microscopy (SEM), XRD analysis identified solid solutions such as Mg_2Sn, Ca_2Sn, Si_2Mg_6Sn, and MgC phases. SEM analysis revealed a uniform distribution of Ca_2C and SiC within the Mg-Sn matrix. While density was determined using Archimedes' principle. Hardness and wear resistance were measured, where test specimens containing 3% SiC and 2% Ca_2C increased up to maximum then decreased.

KEYWORDS
Silicon carbide, mechanical properties, mg-sn-ca_2c alloys, powder metallurgy.

INTRODUCTION
Magnesium alloys are widely used in transportation, electronics, aerospace, and automotive sectors due to their low density and high specific strength. Their advantages include high hardness, effective damping, excellent thermal conductivity, and electromagnetic shielding. However, traditional magnesium alloys face limitations like low ductility, insufficient mechanical strength, and poor corrosion resistance, restricting their industrial applications, [1, 2].

Enhancing the mechanical characteristics of magnesium alloys is a prerequisite for their commercial usage. Consequently, the creation of magnesium alloys to improve their mechanical qualities is required, [3]. Internal galvanic corrosion of magnesium alloys is affected by impurities, lattice imperfections, texture, and the less stable passive hydroxide film compared to aluminum, titanium and stainless steel, [2 – 4].

Improved purity Magnesium has the lowest corrosion rate among galvanic corrosions, but its low strength and poor formability make it challenging to use [5] .Alloy development necessitates extra procedures like as deformation and heat treatment to alter the microstructure in order to get around Mg restrictions [6]. Due to its suitable solubility and precipitate hardening capability, Sn is frequently found in magnesium alloys [7].

The Mg-Sn system shows limited solubility at room temperature but a much higher limit at 561 °C. Research has focused on improving the age hardening response of Mg-Sn alloys by adding various alloying elements. The phases in these alloys also affect corrosion characteristics, with Mg_2Sn being the most compatible, followed by $Ca_{2-y}Mg_xSn$ and Mg_2Ca[8]. Research shows that adding calcium improves creep resistance and mechanical strength. Bakhsheshi-Rad et al., [9], studied Mg-0.5Ca-xZn alloys and found that zinc addition up to 1% reduces corrosion rate, but increasing zinc content to 9% raises the corrosion rate. The total strength of the produced composites is increased by reinforcing the Mg-Sn alloy with a hard ceramic material, such as SiC-Ca_2C, that has an excellent and uniform distribution because of its high ductility and low mechanical properties.

The goal of this work is to make the Mg-Sn alloy a better material for mechanical purposes by strengthening it with a hybrid Ca_2C-SiC addition at varying percentages.

EXPERIMENTAL

Table 1 provides the compositions of the developed powder metallurgy samples (PMP). Based on these compositions, Mg-Sn-Ca_2C-SiC alloys with varying Ca_2C-SiC contents were prepared using the powder metallurgy technique. A constant ratio of Mg-Sn (93 wt. % to 2 wt. %) was mechanically mixed, followed by the addition of SiC and Ca_2C in varying proportions. The composite powders were milled at a ball-to-powder ratio of 10: 1, a speed of 200 rpm, for 8 hours. The resulting mixture was compacted using a uniaxial press under a pressure of 500 MPa. The compacted samples were sintered in a vacuum furnace at 400°C for one hour. The phase structure and microstructure of the sintered samples were analyzed using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Density was measured using Archimedes' principle. Hardness and wear resistance were evaluated using hardness testing and pin-on-disk devices, respectively.

Characterizations and Mechanical Properties

The crystal structure of the sintered samples was studied by X-ray diffraction (XRD, X'pert PAN alytical with 1.5405 Å of CuKα radiation). The surface morphology of the sintered pellets was examined using a scanning electron microscope (SEM- JSM-6360, JEOL, Japan).

Table 1 Chemical composition of $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys.

Sample	Mg	Sn	CaC	SiC
S1	93%	2%	5%	0%
S2	93%	2%	4%	1%
S3	93%	2%	3%	2%
S4	93%	2%	2%	3%
S5	93%	2%	1%	4%
S6	93%	2%	0%	5%

RESULTS AND DISCUSSION

Phase Structure by XRD

Fig. 1 shows the XRD patterns of $Mg_{0.93}Sn_{0.2}$ $(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys. The results show that the alloys mainly include the α-Mg, Mg_2Sn, Ca_2Sn, Si_2Mg_6Sn, and MgC phases. It must be mentioned that the Mg_2Sn, Si_2Mg_6Sn, phases are formed during the sintered process according to the binary phase diagram between Mg-Sn and the ternary diagram between Si, Mg, Sn which these phases are formed at a certain temperature for a certain concentration. The presence of these phases indicates successful incorporation of Sn, SiC, and Ca_2C into the magnesium matrix. The formation of Mg_2Sn and Ca_2Sn phases suggests that tin and calcium interact with magnesium, contributing to potential strengthening mechanisms, while Si_2Mg_6Sn and MgC phases result from the interaction of silicon and carbon with the alloy, further enhancing its mechanical properties. These phases may act as reinforcing particles, contributing to the improved hardness and strength of the alloy. Additionally, the presence of carbide phases could enhance wear resistance and thermal stability. The sharp peaks in the XRD pattern indicate good crystallinity, while any potential peak broadening could suggest microstructural refinement or internal stresses caused by the addition of SiC to the $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys.

Microstructure Investigation

The microstructure of the Mg-Sn-SiC-Ca_2C composite samples was examined using scanning electron microscopy (SEM). The primary focus of the analysis was on the effect of varying the ratios of silicon carbide (SiC) and calcium carbide (Ca_2C) while keeping magnesium (Mg) and tin (Sn) concentrations constant. The SEM images revealed distinct microstructural changes as the SiC content increased and Ca_2C content decreased. In samples with higher SiC content, a more uniform distribution of SiC particles was observed, which contributed to improved particle dispersion and refinement of the grain structure. These images also showed that the SiC particles

were well embedded within the Mg-Sn matrix, forming a strong interfacial bond, which can enhance the composite's mechanical properties.

In contrast, the reduction in Ca_2C content led to a noticeable decrease in carbide inclusions, resulting in a more homogeneous matrix. The diminished presence of CaC particles, which are larger and more irregular in shape compared to SiC, contributed to the overall improvement in the matrix continuity and reduced porosity levels.
Generally, the SEM analysis confirmed that increasing SiC at the expense of Ca_2C has a beneficial effect on the composite microstructure, leading to finer grain sizes, reduced porosity, and better particle distribution, which are expected to enhance the material's mechanical performance.

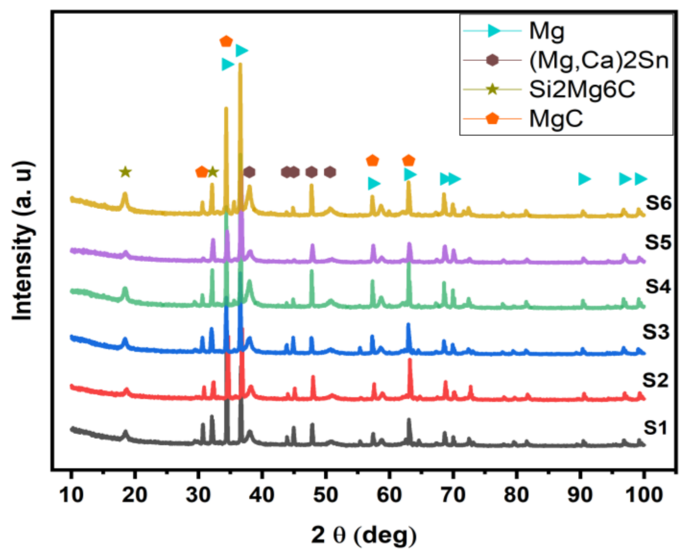

Fig. 1 XRD of $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys.

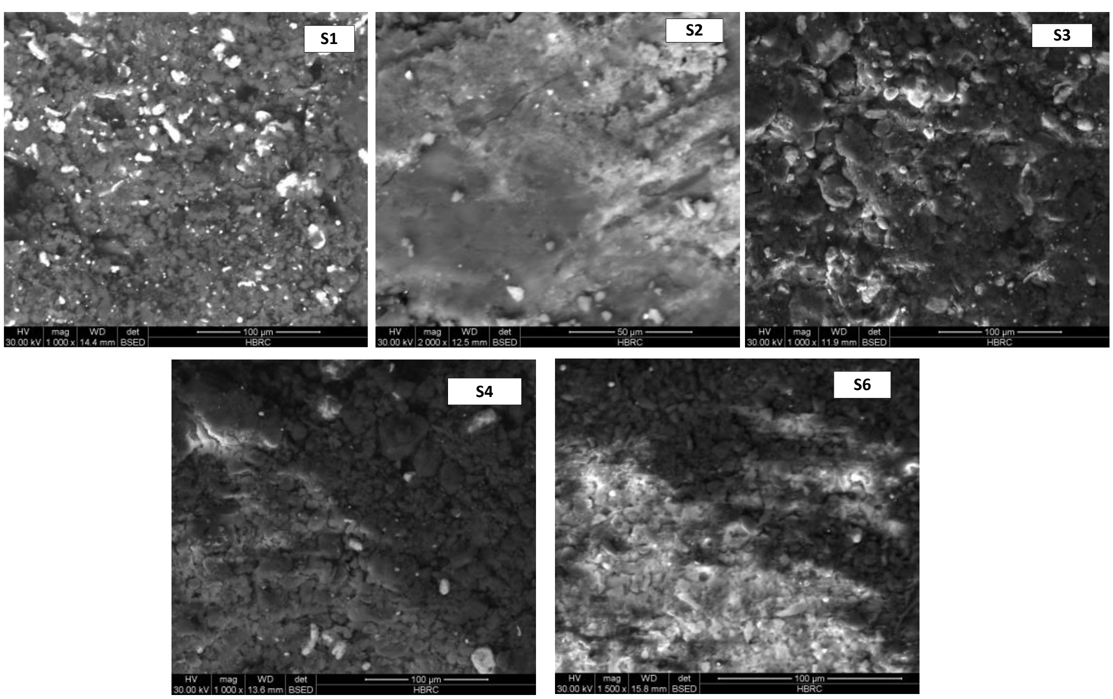

Fig. 2 SEM analysis of $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys.

Density Measurements

Figure 3 shows the relation between the density matrix of the prepared samples and the reinforcement materials added to magnesium-tin matrix. It is clear that the density of Mg (1.749 g/cm^3) was increased by the addition of 2% Sn +5% Ca_2C, this is due to the higher density value of Sn (7.3 g/cm^3) and Ca_2C 2.2 g/cm^{3}than Mg metal, in which reinforcing a low density metals such Mg with a denser particles improves the density, [10].

There are a gradually increases in the density of all the prepared samples by the addition of different propositions from Sn, SiC, andCa_2C. This is owing to the higher density value of them than that of Mg, [12]. It must be mentioned that the density was improved also due to the solid solutions formed during the sintering process. In which this release to the good interaction and complete solubility between all the composite constituents which enhances deificationon, [11 – 13]. It is clear from the curve that the density was increased gradually up to sample S4 which contains 3wt.%SiC and 2 wt.% Ca_2C, then decreased for S5. This may be attributed the highest ratio of SiC in sample 5 which reached to 4wt.% that cause the formation of pores SiC with the high ratio that acts as an internal barrier which hinders densifications.

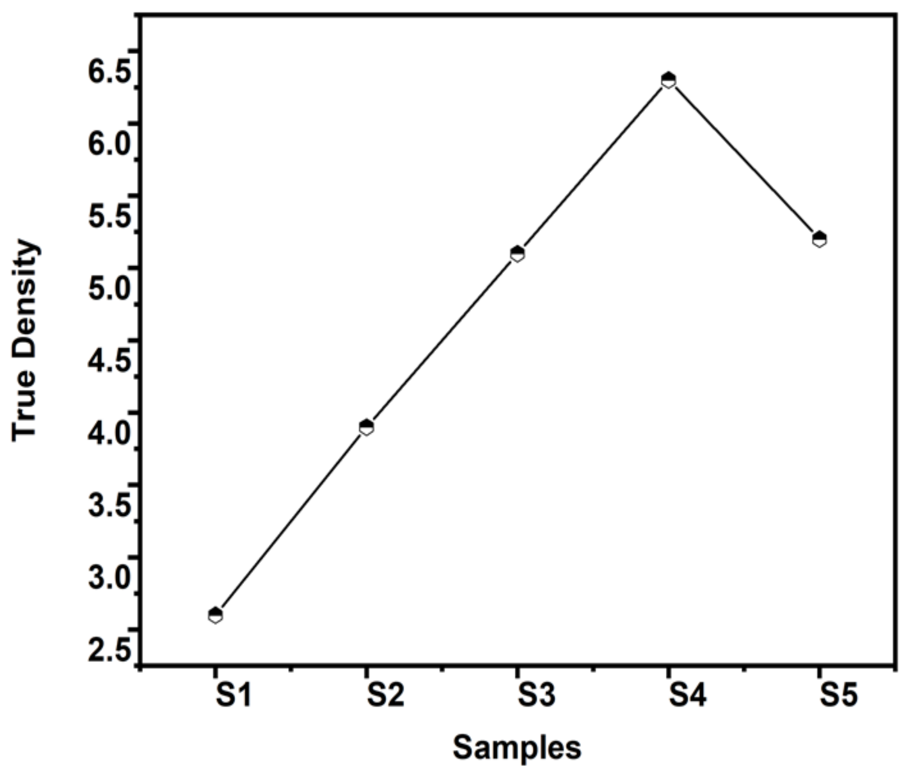

Fig. 3 The behavior of relative density of the Mg-Sn-SiC-CaC alloys.

Mechanical properties

Vickers Hardness Test

Figure 4 shows the effect SiC/Ca_2C additions on the hardness values of Mg-Sn reinforcing alloy in which reinforcing a soft and malleable metal with hard ceramic materials improve the hardness of the overall prepared composite. Vickers hardness increases gradually by addition of both SiC/ Ca_2C up to sample number 4 that contains 4 % SiC, that recorded to highest hardness value due to the high SiC hardness (2563HV). Then it decreases for S5 sample that contains 4 % SiC, 1 % Ca_2C. This may be explained by the higher porosity percent of this samples detected by density results, both SiC/Ca_2C in the Mg-Sn alloy has a good rule in the important of the all hardness of the alloy. This could be due to the presence of hard ceramic materials, [13]. Generally, reinforcing a ductile alloy such as Mg-Sn with a ceramics particle like SiC Ca_2C improves the over alloy hardness of the prepare composite. Especially when these ceramic particles and distributed homogenously all over the Mg-Sn alloy matrix as detected from the SEM results.

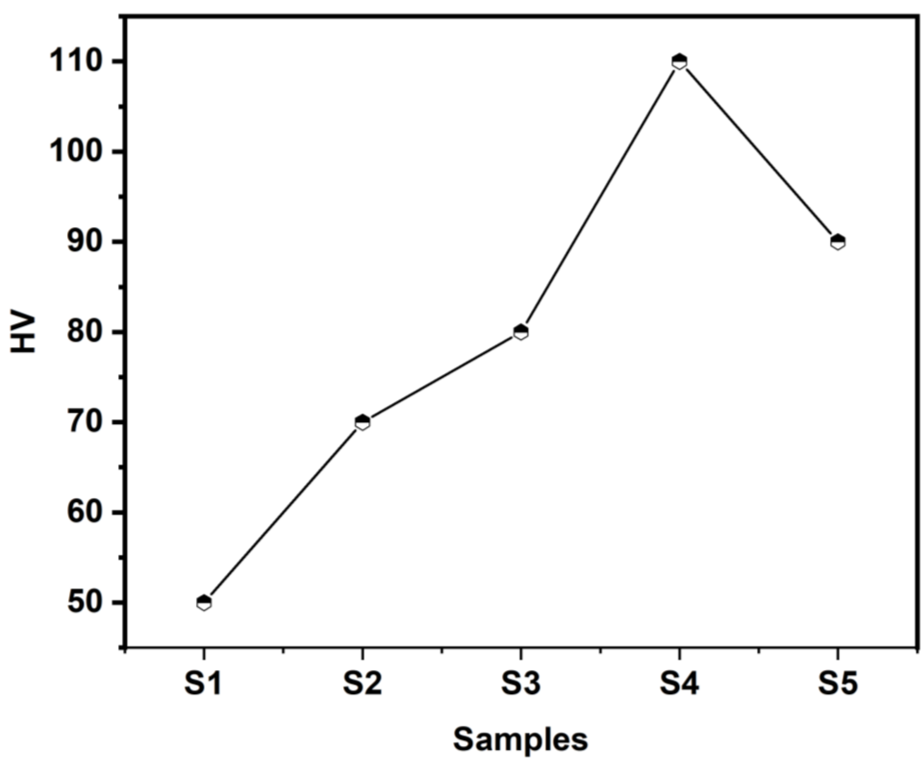

Fig. 4 Vickers hardness trends in $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys composites.

Mechanical Wear

Figure 5 shows the impact of reinforcing the ductile $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys on the wear resistance. The curve shows a gradual decrease in the weight loss during the wear process by SiC/Ca_2C additions. This is may be attribute to the high

strength and hardness of the SiC/Ca_2C particles that are impeded homogeneously in the Mg-Sn matrix alloy. This in accordance with the density hardness results. This is compatible with the density hardness results.

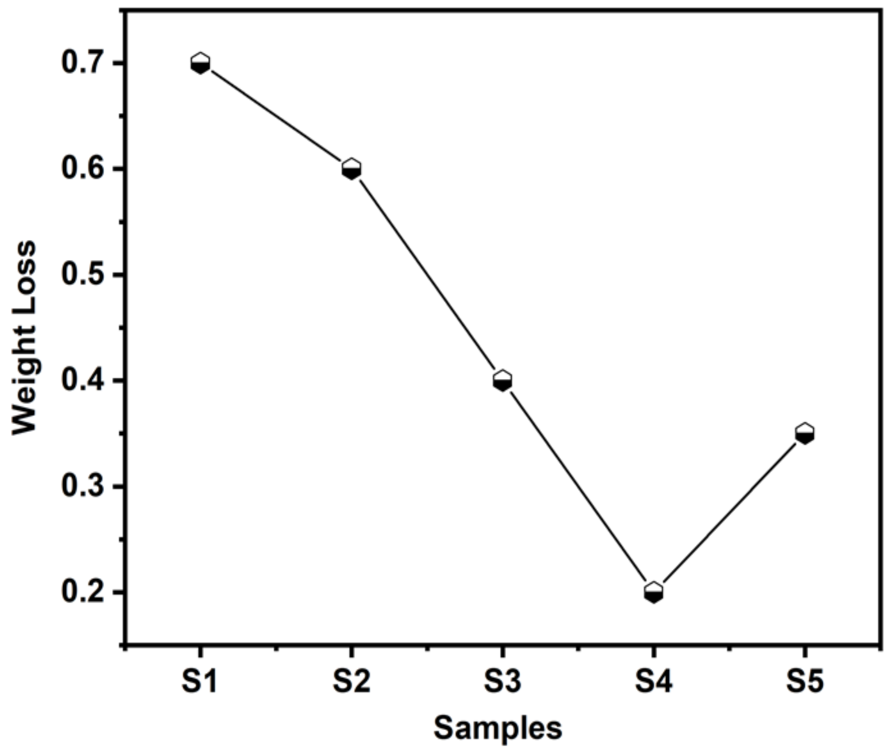

Fig. 5 The behavior of the weight loss of the $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys composites.

CONCLUSIONS

The findings lead to the following conclusions:

1. A $Mg_{0.93}Sn_{0.2}(Ca_2C)_{(0.5-x)}(SiC)_{(x)}$ alloys with varying SiC proportions can be synthesized using powder metallurgy.

2. X-ray diffraction analysis identified solid solution phases such as α-Mg, Mg_2Sn, Ca2Sn, Si_2Mg_6Sn, and MgC during sintering.

3. Scanning electron microscopy showed effective distribution of SiC-Ca_2C in the Mg-Sn matrix.

4. Adding SiC improved density, hardness, and wear resistance.

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