MICROSTRUCTURAL EVALUATION OF IMPACT ZONE OF SIC PARTICULATE REINFORCED AZ91D MAGNESIUM ALLOYS UNDER BALLISTIC IMPACT ON A SPECIALLY DESIGNED GRAVITATIONAL BALLISTIC TEST APPARATUS

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Abstract

The main aim of this study was to design and manufacture the lab-type ballistic test apparatus which does not need firearms that carry out the ballistic test of metallic and composite armor materials, and realization of tests using Mg-based composite materials. To this end, an apparatus that runs without any pressure-related or explosive propulsion system but using gravity instead was designed. The apparatus allows creating the effect of different firearms and ammunition ranging pistols to rifles. Since the apparatus creates the impact of firearms (which have muzzle velocities up to 900 m/s) using gravity, its terminal velocity only reaches to 3.2 m/s and it travels for only 0.32 s after fired (ran). Mg composites with different amount and size SiC particulate reinforcements were examined on this specially designed apparatus using .556 caliber ammunition.

Keywords: Magnesium, composite, ballistics.

1. INTRODUCTION

High-technology companies increasingly rely on the technical and economic potential of innovative materials, as well as their workmanship and machining abilities, as a strategy for successful competition on the market. Additionally, politics and the public are demanding a more economical use of scarce primary energy sources. One of the key goals for the next decades will be the further reduction of emissions to lower the growing environmental impact. Taking this into consideration, the use of light metals as construction materials is generally viewed as becoming of key importance in the future. Although magnesium alloys are fulfilling the demands for low specific weight materials with excellent machining abilities and good recycling potential, they are still not used to the same extent as the competing materials aluminum and plastics. One of the reasons is the fairly high priced base material, coupled with the partial absence of recycling possibilities. On the other hand, the variety of magnesium available to the consumer is still limited to a few technical alloys. Unfortunately, there is a lack of know-how in the use of magnesium, not least within the companies dealing with the machining and application of construction materials. As a result, the industry still tends to use "conventional" materials instead of magnesium alloys [1].

Metal matrix composites (MMCs), like all composites, consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. Generally, there are two phases, e.g., a fibrous or particulate phase, distributed in a metallic matrix. Examples include continuous A1203 fiber reinforced aluminum matrix composites used in power transmission lines; Nb-Ti filaments in a copper matrix for superconducting magnets; tungsten carbide (WC)/cobalt (Co) particulate composites used as cutting tool and oil drilling inserts; and SiC particle reinforced aluminum matrix composites used in aerospace, automotive, and thermal management applications [2].
Silicon carbide in particulate form has been available for a long time. It is quite cheap and commonly used for abrasive, refractory, and chemical purposes. Particulate SiC is processed by reacting silica in the form of sand and carbon in the form of coke at 2400°C in an electric furnace. The SiC produced in the form of large granules is subsequently comminuted to the desired size. Two types of SiC particulate reinforcement are shown in Fig. 1.

Fig. 2. SiC particulates with angular and rounded morphology, respectively [2]. Smaller ceramic particulates with a little amount volume fraction have significant influence on microstructure and mechanical properties of particulate reinforced magnesium matrix composites. Chen and his colleagues’ study illustrated that a little amount of 1–2 μm SiC particulates had great effect on grain refinement of AZ91D magnesium alloy [3].

Smaller particulate reinforced composites had been produced by a variety of methods: stir casting, disintegrated melt deposition, powder metallurgy, etc. However, stir casting method is preferred to other techniques for its capability in producing complex shapes at a high production rate and low costs [4-6]. AZ91D magnesium alloy is the most popular commercially available magnesium alloy. This alloy shows superior castability and good mechanical properties combined with good corrosion resistance for the high purity versions of the alloy. Typical applications include transmission casings, valve covers, intake manifolds, brackets, pumps, etc. Mg–Al–Zn based alloys like AZ31, AZ61, AZ80 and AZ91x are, in general, utilized for applications at ambient or slightly elevated temperatures primarily in the automotive and electronic industry. They successfully combine acceptable mechanical properties with good castability and relatively low production costs.

2. EXPERIMENTAL PROCEDURE
AZ91D magnesium alloy (supplied by a local foundry in Istanbul) was selected as matrix alloy, and the chemical composition of AZ91D alloy was given in Table 1. SiC particulates (supplied by GoodFellows in U.K.) with the average sizes of 7 μm and 32 μm were used as reinforcement.

Table 1. Chemical composition of cast specimens

<table>
<thead>
<tr>
<th>Alloying Element</th>
<th>Al</th>
<th>Mn</th>
<th>Zn</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Ni</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt. %</td>
<td>8.70</td>
<td>0.25</td>
<td>0.70</td>
<td>0.02</td>
<td>0.004</td>
<td>0.007</td>
<td>0.00015</td>
<td>balance</td>
</tr>
</tbody>
</table>

AZ91D magnesium alloys reinforced with SiC particulates (SiCp/AZ91D) containing three volume fractions (2, 4 and 8 wt.%) were fabricated by stir casting. The whole fabrication process was conducted in a protective atmosphere of CO₂ and argon to avoid oxidation in an induction furnace. The alloy was molten at
700 °C, and then cooled to 600 °C where the matrix became semi-solid. As the SiC particulates were added into the molten, the melt was stirred for 30 min and then was rapidly reheated to 700 °C before casting. The melt was poured into a preheated cast iron mold between 300-400 °C (Fig. 2). After solidification, specimens were machined to place in gravitational ballistic test apparatus shown in Fig. 3.

![Fig. 2. Melting process and mold.](image)

![Fig. 3. Specially designed test apparatus and indenters simulation ammunition.](image)

### 3. RESULTS AND DISCUSSION

All specimens were subjected to ballistic impact test using parameters simulating an M16A4 firing 5.56×45mm NATO ammunition. Impact zones captured using a stereo-microscope were given in Fig. 4.
Fig. 4. Macrographs of impact zones (a-e; f was destroyed during test).

Composition of each composite is given in Table 2.

<table>
<thead>
<tr>
<th>Designation</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. % SiC</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>SiC particle size (μm)</td>
<td>7</td>
<td>32</td>
<td>7</td>
<td>32</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>Maximum diameter (mm)</td>
<td>5.76</td>
<td>5.83</td>
<td>5.63</td>
<td>6.02</td>
<td>5.95</td>
<td>X</td>
</tr>
<tr>
<td>Penetration depth (mm)</td>
<td>6.12</td>
<td>6.25</td>
<td>5.95</td>
<td>6.35</td>
<td>6.30</td>
<td>X</td>
</tr>
</tbody>
</table>

- The SiCp/AZ91D composites were successfully fabricated by stir casting under CO₂/Ar atmosphere.
- Impact strength of composites reinforced with 7 μm SiC particulate was higher than those reinforced with 32 μm.
- Increasing amount of 32 μm SiC particulates in matrix did not increase impact strength.
- Exceeding amount (over wt. 4%) of 32 μm SiC particulates led the test pieces to tear and made further examination impossible.
It has been concluded that SiC particulates with smaller particle size could refine the grain size of AZ91 matrix. This refining of grain size could increase the impact strength of overall structure. The addition of submicron-SiC particulates led to the increase of micro-hardness and elastic modulus of SiCp/AZ91 composites, and they increased with the increasing of volume fraction of submicron-particulates in the AZ91 matrix.

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REFERENCES