Effect of Aluminium coating on the Ferro-Silica-Magnesium alloys’ hardness and corrosion rate

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Abstract. This paper studied the effect of Aluminium coating on the Fe-Si-Mg alloys surface to its hardness and corrosion rate. The Fe-Si-Mg-Al was formed from Fe-Si-Mg Powder Alloy, which was coated by Aluminium (Al) with the composition of (0; 2.2; 6.0; 10.2) wt%. The mechanical alloying was applied to conduct a wet mixing with the ball mill in a shaker mill for two hours. The powder was then dried and compress under eight tons of pressure for three minutes. The sample was then sintered in a tabular furnace with a temperature of 1000°C for two hours and 5C/minutes of heating rate. Furthermore, the natural cooling rate was applied to reach room temperature. The sample was examined in an XRD to analyze the phase and tested under a SEM-EDX to evaluate the morphological structure as well as its dispersion. The results showed that the hardness rise as the increment of Al. It is because of the oxidation of Fe, Si, and Al, which formed Fe₂O₃, SiO₂, and Al₂O₃ filled out the gap. The development of Al decreased the corrosion rate. Al with the composition of (6.0 wt%) was the lowest corrosion rate which the value of 1.013x10⁻³ mmpy.

1. Introduction
The advanced material is essential in the automotive and power plane industry, which operates the factory under high-temperature conditions. These industries need a material with specials mechanical and physical properties such as robust, light, elastic, tough, resistance to the impact, corrosion and high-temperature condition. The study of SiCp filler to the corrosion rate of Metal Matrix Composites (MMCs) has been conducted [1]. Here, the material process and composition are essential for the mechanical and physical properties [2-6]. The addition of Al to the Fe, Si, Mg alloy in the high-temperature condition has also been studied [7,8], whereas the Fe is matrix, while Si-Mg is alloy. Si alloy increases the hardness [9,10] because it can oxidize and formed SiO₂, while Mg alloy rise the corrosion resistance [11]. The addition of Al to the alloy in the high-temperature sintering process is working as an adhesive [12,13]. This study conducted the synthesis of Ferro-silica-magnesium with various addition of Al to produce a lump composition. The phase, structure, hardness, and corrosion rate of this composition is analyzed to get an appropriate advance material.

2. Experimental procedure
This study analyzed the addition of Al into Ferro-silica-Magnesium (Fe-Si-Mg) alloy. The composition of Ferro-silica-Magnesium is 30.2, 55.3, 12.1, and 2.4 wt% Fe, Si, Mg, and other material, respectively. The Al powder is added to Fe-Si-Mg powder alloy with various compositions of (10.2; 0; 2.2; 6.0) wt%. These materials were mixed for wet grinding in a shaker-mill and then compressed under eight tons of
pressure for five minutes. This sample was heated up in a furnace with a temperature of 1000oC. The sample was cooled down into room temperature, polished with silicon carbide (SiC), and then analyzed. The sample was analyzed under the XRD to evaluate the phase and then tested under SEM/EDX to study the microstructure, the homogeneity, dispersion rate, and percentage of each element. After that, the hardness was tested in the Hardness Vickers. Finally, the process was closed with the corrosion test. The addition of Al to the Ferro-silica-magnesium alloy was studied to obtain its physical and mechanical properties.

3. Results and discussion

3.1. The X-Ray diffractometer

The XRD analysis was conducted under the Shimadzu XRD-7000, CuKα radiation with =1.5406 Å. The result was showed in Figure 1.

![Figure 1](image.png)

**Figure 1.** The XRD plot of Al addition to Fe-Si-Mg with variations composition of (a) 0.0 wt%, (b) 2.2 wt%, (c) 6.0 wt%, and (d) 10.2 wt%.

Figure 1 showed the XRD diffraction plot of Fe-Si-Mg with various concentration of Al (0.0, 2.2, 6.0, 10.2) wt%. The SiO₂ and Fe₂O₃ phase appeared. The FeSi₂ phase was a polycrystalline structure with the HKL field (420), (221), (101), (422), (200), (211), (220). Among the peaks of FeSi₂ diffraction, there were also some peaks with field HKL (001), (101), (202) and (211), have a higher intensity when compared to the top of the field HKL other. In addition, it is detected at an angle of 2θ between 17° to 27° formed amorphous phase SiO₂. The SiO₂ layer can act as a protective coating on the sample because it is exposed to oxygen into the alloy. At the three main peaks of the phase FeSi₂ each sample is at the angle of diffraction 2θ (± 45°, ± 50° and ± 79°). The SiO₂ phase at the angle of diffraction 2θ (± 23° and ± 25°) with the areas of orientation of HKL (101) and (110) and has the size of crystals that tend to decline and the lattice of the grid increases with the increase of Al elements.
3.2. Microstructures
The microstructures were tested under SEM-EDX Jeol JSM 6510LA with 2000x magnifications. Figure 2 showed the Fe-Si-Mg morphology with the Al addition of (0.0, 2.2, 6.0, 10.2) wt%. The oxygen was dispersed uniformly in each sample and showed that the sample was oxidized. This was caused by the grain boundary of Si with oxygen and formed SiO2 in the sintering process. The Fe and Si were bound and formed FeSi2. Based on the EDX tested, the addition of Al (6.0 wt%) has the lowest value of oxygen; therefore, the sample was not corroded easily.

![SEM-EDX images](image1)

| The Element | Wt% |
|-------------|-----|
| O K         | 59.05 |
| Mg K        | 3.89 |
| Al K        | 2.00 |
| Si K        | 28.92 |
| Fe K        | 6.15 |
| **Total**   | **100.00** |

![SEM-EDX images](image2)

| The Element | Wt% |
|-------------|-----|
| O K         | 33.74 |
| Al K        | 7.58 |
| Si K        | 37.06 |
| Fe K        | 21.63 |
| **Total**   | **100.00** |

![SEM-EDX images](image3)

| The Element | Wt% |
|-------------|-----|
| O K         | 28.05 |
| Mg K        | 1.34 |
| Al K        | 5.57 |
| Si K        | 40.92 |
| Fe K        | 29.69 |
| **Total**   | **100.00** |

![SEM-EDX images](image4)

| The Element | Wt% |
|-------------|-----|
| O K         | 54.01 |
| Mg K        | 2.49 |
| Al K        | 3.32 |
| Si K        | 22.78 |
| Fe K        | 17.4 |
| **Total**   | **100.00** |

Figure 2. SEM-EDX sample of Fe-Si-Mg Microstructure with a various addition of Al (a) Al (0.0 wt%), (b) Al (2.2 wt%), (c) Al (6.0 wt%), (d) Al (10.2 wt%).
3.3. **Hardness vickers**

The hardness was measured with the aid of Hardness Vickers. The results were written in terms of hardness as the function of indentor for each lump sample with the Al addition of (0.0, 2.2, 6.0 and 10.2) wt% as shown in figure 3. Figure 3 effect of the addition of Al in lump Fe-Si-Mg, that the entire sample of the hardness value at each indentor point is slight fluctuations and tends to stabilize. For chart (a) samples without the addition of Al (0.0 wt%), the chart (b) with the addition of Al (2.2 wt%), the chart (c) with the addition of Al (6.0 wt%) and graphs (d) with the addition of Al (10.2 wt%). The addition of Al seems to make violent values tend to rise, but for samples (c) with the addition of Al (6.0 wt%) Has the greatest hardness of the average of 59.04 kg/mm² when compared to other samples. It was because of the annealing process at the temperature of 1000°C. The XRD tested shown that besides FeSi and FeSi2 phase, there was also SiO₂ and Fe₃O₄ phase. But, at the Al addition of (10.2 wt%), the sample was reached the saturation point. As a consequence, the hardness was decreased.

![Figure 3](image)

**Figure 3.** The hardness Vickers of Fe-Si-Mg alloy with various Al content (a) 0.0 wt%, (b) 2.2 wt%, (c) 6.0 wt%, (d) 10.2 wt%.

3.4. **Corrosion rate**

The corrosion rate was measured by the polarization methods. This measurement was applied to Fe-Si-Mg sample with the various addition of Al (0.0 wt%, 2.2 wt%, 6.0 wt% and 10.2 wt%) with the aid of Potensiosstat Gamry Reference 600. The media was NaCl, and the results were displayed in the table 1.

| Sample          | Al (0.0 wt%) | Al (2.2 wt%) | Al (6.0 wt%) | Al (10.2 wt%) |
|-----------------|--------------|--------------|--------------|--------------|
| Surface Area (cm²)  | 0.692        | 0.523        | 0.537        | 0.642        |
| Electrolyte Solution | NaCl 3.5% (b/v) | NaCl 3.5% (b/v) | NaCl 3.5% (b/v) | NaCl 3.5% (b/v) |
| Temperature      | 26.6         | 26.4         | 26.3         | 26.4         |
| Icorr (mA)       | 1.421 x 10⁻³ | 1.256 x 10⁻³ | 0.727 x 10⁻³ | 0.976 x 10⁻³ |
| Ecrr (mV)        | -896.6       | -684.4       | -913.7       | -793.1       |
| DENSITY (g/cm³)  | 1.49         | 1.64         | 1.69         | 1.88         |
| Corrosion Rate (mmpy) | 1.342x10⁻³ | 1.120x10⁻³ | 1.013x10⁻³ | 1.249x10⁻³ |
| FW              | 9.32         | 9.32         | 9.32         | 9.32         |

![Figure 4](image)

**Figure 4.** showed a potential diagram as the function of current. (a) Fe-Si-Mg with no addition of Al (0.0 wt%), (b) Fe-Si-Mg with the addition of Al (2.2 wt%), (c) Fe-Si-Mg with the addition of Al (6.0 wt%) and (d) Fe-Si-Mg with the addition of Al (10.2 wt%). The corrosion test results were shown in table 1. The corrosion rate as the function comparable to the density of corrosion current (Icorr), and is influenced by the sample surface area. Based on that data, it can be seen that the lowest corrosion rate
is found in Fe-Si-Mg samples with the addition of Al (6.0 wt%), i.e. 1.013 x10^{-3} mmpy. There is a tendency, that the increasement of filler Al composition in a lump Fe-Si-Mg caused the decrement of corrosion rate.

Based on the XRD analysis, the FeSi2, SiO2, and Fe2O3 phases formed in the annealing process. Si and Fe were more convenient to bound with the oxygen rather than Aluminium. The corrosion rate was decreased when Al (10.2 wt%) was added to the alloy. Therefore, the hardness and corrosion-resistant were increased by the development of Al concentration in the Fe-Si-Mg lump.
Figure 4. The diagram of polarization corrosion measurement of Fe-Si-Mg samples with various addition of Al (a) Al (0.0 wt%), (b) Al (2.2 wt%), (c) Al (6.0 wt%), (d) Al (10.2 wt%).

4. Conclusion
The Al has been added into Al-Si-Mg alloy with various concentrations of (0.0, 2.2, 6.0, 10.2) wt%. The addition of Al (6.0wt%) to the Al-Si-Mg Alloy, which was conducted via a powder metallurgy process with the annealing of 1000, showed the highest hardness value and the lowest corrosion rate. At the composition of (6.0wt%), Al filled out the vacancies grain boundary that left out by the oxygen and caused the grain bounding touching area to become extensive. Therefore, the sample becomes hard and solid.

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