The effect of fluxing material and method on the inclusion content of strontium modified A356.2 at Indonesia Asahan Aluminium Company

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Abstract. Aluminium foundry alloys are often contaminated with non-metallic inclusion particles in forms of oxides, carbides, and spinel. These inclusions can lead to significantly reduce of mechanical properties of aluminium foundry alloy. Fluxing treatment is one of the conventional methods for removing inclusions and oxides from the melt to enhance the quality of aluminium foundry alloy. In this study, we used several recipes of metal treatments and flux dosages and investigate the quality of A356.2. Filtration graphic by Prefil Footprinter and hydrogen content data by AlScan Hydrogen Analyzer were obtained to fully analyze the mechanism and get the best fluxing parameters.

1. Introduction
Primary aluminium foundry alloy A356.2 is widely used as structural shaped casting in automotive industry. This type of aluminium alloy is mainly produced by Aluminium Smelter Company which has electrolysis cell to ensure the purity of composition of aluminium foundry alloy. Indonesia Asahan Aluminium company or INALUM is an Aluminium Smelter Company located in Kuala Tanjung, North Sumatera, Indonesia that since 2017 has been commercially producing aluminium foundry alloy (A356.2) and billet (6063, 6061, 6005) with annual capacity of 90,000 tpa and 30,000 tpa respectively. The development of product quality particularly aluminium foundry alloy A356.2 is an essential requisite to the company future in order to ascertain the premium quality castings of customers.

The end-users of A356.2 requires the inclusions content and porosity to be minimized to eliminate the harmful effect on mechanical properties. The main inclusions of aluminium foundry alloy are aluminium oxide (Al₂O₃) as dispersed particles or oxide films, aluminium carbide (Al₄C₃), magnesium oxide (MgO), spinel (MgAl₂O₄), cuboid (MgAl₂O₄), silicon oxide (SiO₂), salt (MgCl₂, NaCl₂, CaCl₂), bone ash (Ca₃(PO₄)₃), aluminium nitride (AlN), iron/manganese oxide, silicon particle, grain refiner (TiB₂/TiC), aluminium boride (AlB) and titanium aluminide (TiAl₃) [1] [2] [3] [4] [5] [6] [7] [8].

There are several ways to reduce inclusions during aluminium foundry alloy production including maintaining the quality of raw materials, efficient melt treatment method (alloying, fluxing, stirring, skimming, settling or calming), efficient degassing and filtering process. In this report, the effect of alloying recipe consists of several fluxing scheme and dosage to the inclusion content of the aluminium foundry alloy A356.2 are being discussed. The analysis is based on production-scale test at aluminium foundry alloy line at INALUM.
2. Method

2.1. Melt preparation

Table 1 shows the chemical composition of A356.2 modified by Strontium as a target of the production at INALUM. This alloy was made by combination of molten aluminium from INALUM reduction cell with several master alloy including silicon metal 441, magnesium metal, aluminium titanium (AlTi80) and aluminium strontium (AlSr10) as modifier.

| Alloy | Amount (wt%) of the following elements |
|-------|---------------------------------------|
|       | Si | Mg | Cu | Sr | Mn | Ti | Fe | Zn |
| A356.2| 6.7 – 7.3 | 0.34 – | ≤ 0.01 | 0.022 – | ≤ 0.02 | 0.10 – | ≤ 0.10 | ≤ 0.02 |
|       | 0.42 | 0.030 | 0.20 |

2.2. Production-scale test

The experimental method of this work is divided into several scenarios as described in Table 2. Production was carried out by using reverberatory holding furnace (Chugairo, Japan modified by Allied Minerals, Canada), electro-magnetic stirrer (ABB, Canada), casting line (o.d.t Engineering, Australia), degassing (STAS, Canada) and filter box (Drache, Germany). Fluxing was done by manual spraying over melt surface and stirred properly by electromagnetic stirring. The temperature of casting was around 730 – 740 °C as per the exit furnace.

| Code | Alloying Recipe | Flux Dosage | Degasser Rotor | Degasser Skimming |
|------|----------------|-------------|----------------|-------------------|
| A1   | R0             | 1.5         | 4              | No                |
| A2   | R0             | 1.5         | 0              | No                |
| A3   | R1             | 1.5         | 2              | No                |
| A4   | R1             | 3           | 2              | No                |
| A5   | R1             | 3           | 4              | No                |
| A6   | R2             | 1.5         | 2              | No                |
| A7   | R2             | 3           | 4              | No                |
| A8   | R2             | 1.5         | 4              | No                |
| A9   | R2             | 1.5         | 4              | Yes               |

Detail of the alloying recipes is shown in Figure. 1 a – c.
Figure 1. a–c Alloying recipes of aluminium foundry alloy A356.2 at INALUM.

The composition of flux used is shown in Table 3.

| Compound | Amount (wt%) |
|----------|--------------|
| NaCl     | 48 – 52 (wt%) |
| Na₂SiF₆  | 5 – 7 (wt%) |
| KCl      | 32 – 36 (wt%) |
| NaF      | 9 – 11 (wt%) |
| NaCl     | 48 – 52 (wt%) |
2.3. **Inclusion measurement**

Inclusion measurement was done during the production process (in process) by using Prefil Foot printer (ABB, Canada). Inclusion is represented as the filtration graph during filtering at the equipment. The graph shows as filtered weight (kg, max of 1.4 kg) vs filtration time (s, max of 150 s), which means that high filtered weight with short filtration time (high slope) will have less inclusion content in metal. Figure 2 shows the inclusion content measurement activity at INALUM Plant.

![Figure 2. Prefill foot printer measurement at INALUM plant.](image2)

2.4. **Hydrogen content measurement**

Hydrogen content measurement was done also during the production process (in process) by using AlScan Hydrogen Analyzer (ABB, Canada). Hydrogen content is directly shown by the equipment in mL per 100 g of molten aluminium. Fig. 3 shows the hydrogen content measurement activity at INALUM Plant.

![Figure 3. AlScan hydrogen analyzer measurement at INALUM plant.](image3)
3. Results and discussions

3.1. The effect of alloying recipes to the inclusion
The result of Prefil Footprinter measurement under different types of alloying recipes is summarized at Figure 4. Based on the measurement results, the comparison of A1, A5 and A8 indicates that alloying recipe R2 is better than R1 and R0. This proves that silicon oxide formation was reduced by changing the batching cycle from R0 to R1, furthermore the effective of fluxing step is sufficient to better improves the metal cleanliness on R2.

![Filtration Curve](image)

Figure 4. Filtration curve of selected experiments.

3.2. The effect of flux dosage to the inclusion
In this work, two sets of flux dosage, 1.5 kg/T and 3 kg/T were observed. Based on the measurement results on Fig. 2, the inclusions content tends to have different values by the changing of the fluxing dosage. Comparison on result A2 with A4 and A7 with A8 indicates that 1.5 kg/T flux dosage tends to have better cleanliness compare to 3 kg/T. High flux content will lead to the formation of Salt inclusion which particularly decreases the cleanliness of aluminium.

3.3. The effect of degassing process to the inclusion
During degassing process molten aluminium will be purged with N\textsubscript{2} gas by rotary cylinder head. The speed of the rotor was operated at 770 rpm with 70 slpm of argon flowrate. As the vortex formed in the molten aluminium, some oxides may occur on the top of molten aluminium surface. This is shown as the measurement result A8 in comparison with A9. Result A8 was operated without skimming on the metal surface at degasser while A9 was skimmed. The skimmed test showed better metal cleanliness with fast filtration time (Figure 2).

On the other hand, graphite rotor also affects inclusion content as shown on result A1 vs A2, A4 vs A5 and A6 vs A8. Different number of operated rotors has a significant effect to the filtration time. The higher number on operated rotor tend to have lower metal cleanliness or high inclusion content. This is also related to the ABB report on A356.2 of INALUM product [3] that Al\textsubscript{13}C\textsubscript{4} > 3 µm will be
originated from graphite deterioration or any other source of carbon contamination (counted separately as carbides are very hard and because of their size, they are detrimental).

Hydrogen content of each selected experiment was also measured as shown on Fig. 5 and Fig. 6. Based on the experiment, the hydrogen content value depends on the operating rotor of degasser as indicated in Figure 6. 4 rotors degasser has the best reduced hydrogen followed by 2 rotors and 0 rotor respectively. Furthermore, launder temperature also affects the hydrogen content as indicated in Figure 6. This is normal since the solubility of hydrogen is strongly increased as the temperature increased [9].

![Hydrogen Content vs Rotor](image)

**Figure 5.** Hydrogen Content vs Number of Rotor of Selected Experiments.

![Hydrogen Content vs Launder Temperature](image)

**Figure 6.** Hydrogen Content vs Launder Temperature of Selected Experiments.

### 4. Conclusions

Based on the experimental result by production-scale test at INALUM, it can be concluded as follows:
1. Different alloying recipes have different effect on metal cleanliness of strontium modified A356.2. According to this work the best alloying recipe is R2 followed by R1 and R0 respectively.

2. The inclusions content tends to have different value by the changing of the fluxing dosage. Comparison on result A2 with A4 and A7 with A8 indicates that 1.5 kg/T flux dosage tends to have better cleanliness compare to 3 kg/T.

3. Higher number of rotors tends to have lower metal cleanliness this may be caused by graphite deterioration of rotor during casting process.

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