Effect of addition of sodium chloride in sodium nitrate-sodium fluoride-based degasser in aluminum casting

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Abstract. The effect of addition of Sodium Chloride (NaCl) in increasing degasser efficiency on Al-Si12% casting has been carried out. Al-Si 12% casting product mechanical properties are a very important parameter that indicates the quality of the casting product. However, it is a very common phenomenon that the properties of the casting product was reduced by gas porosity defects, which is formed due to high solubility of H₂ at melt temperature of Al-Si 12%. In this investigation, we used NaF and NaNO₃ as degasser with the addition of NaCl in the casting process. The addition of NaCl was variated to see the capability of NaCl as a degasser. The casting process were conducted at melting temperature of 800 °C and pouring temperature of 690 °C. The mechanical properties between casting products that use NaF-NaNO₃ degasser with variated ratio of NaCl addition were measured and compared. The result shows that mechanical properties of Al-Si12 cast product in this research will be decreased along with increasing number of NaCl addition ratio in degasser composition.

1. Introduction

Aluminum is one of the most used material in manufacturing industries such as transportation or construction industries because of its light weight properties. Unfortunately, this properties itself is not enough in industrial aspect, because of the nature of pure aluminum that has low strength. Therefore, it has to be alloyed with other elements like silicon to increase its mechanical properties, such as good castability, high strength-to-weight ratio, and good corrosion resistance [1-3]. Silicon usually was added up to 12%, and it will give good castability properties. The higher number of Si added into aluminum, its thermal expansion coefficient will be lowered. Also, Si was a hard phase, so addition of Si can increase aluminum alloy’s wear resistance [4].

Porosity is one of the major defects in aluminum alloy casting that is detrimental to mechanical properties of the casting products [4-9]. The presence of porosity inside molten aluminum can be found in microstructure test that is represented by black hole on cast product. It can occur because of some factors, either because of gas precipitation in solidification, inability of the liquid metal to feed through interdendritic regions, or turbulent flow during filling process [5,6,8]. Hydrogen is considered to be the only significant gas dissolved in molten aluminum, so it is very important to prevent the precipitation of hydrogen gas inside molten aluminum to reach high quality of the casting product [7]. By increasing the temperature used in casting process, the number of hydrogen gas that can be trapped in molten aluminum will be higher. Hydrogen is the only gas that does not form compounds with...
aluminum, so it has high solubility in liquid aluminum, but very low solubility inside solid aluminum, so when casting product is solidified, it will expelled forming gas pores.

To eliminate hydrogen gas inside molten aluminum, several methods have been studied and applied in industries. Fluxing and degassing are the most common methods that are used in aluminum casting. These methods can lower the number of hydrogen gas by binding the gas and then carried the slag into the surface in the furnace. There has been many studies about degassing methods, such as ultrasonic degassing, re-melting degassing, vacuum degassing, or tablet degassing.

In many researches, the most common tablet degasser that were used are tablet degassing by hexachloroethane (C₂Cl₆). C₂Cl₆ will decompose to form AlCl₃ gas bubbles that will collect hydrogen gas, but because of its tendency to produce noxious odor that will become an environmental problem, its production was prohibited by EU in 1998 [10]. Since the prohibition of C₂Cl₆ tablet degasser, degassing method has been replaced by another method such as purging, lance degassing, and many else.

In this paper, composition of tablet degasser used is changed into sodium nitrate-sodium fluoride-based degasser with the addition of NaCl. NaCl addition in tablet degasser composition was variated, with expectation that it can replace sodium nitrate-sodium fluoride as degasser’s main composition, because NaCl has a lower price, so industries can set a lower cost to produce casting product but with same quality.

2. Experimental

2.1. Making of Degasser
The tablet degasser used is containing 18%wt NaNO₃ in powder forms, 40%wt NaF, and the other 42%wt consists of NaCl, NH₄Cl, Na₂SO₄, and dye. These ingredients were placed in container and then water is poured. Mixer machine was used to mix all of them together. The stirring process then conducted for approximately 30 minutes to help homogenized the mixture. After the mixing process is finished, the mixture then processed and formed into tablet shape using printing machine. The last process in this step is to heat the tablet degasser inside oven at 100 °C for 1 hour to evaporate moistrures inside, mostly water.

For this research, the ratio number of NaCl that was added is variated into 4 different weight ratio, it is 0.2%wt, 0.4%wt, 0.8%wt, and 1.5%wt. The purpose want to be achieved in this research is to know the effect of increasing ratio number of NaCl addition in degassing process.

| Composition | Degasser 1 | Degasser 2 | Degasser 3 | Degasser 4 |
|-------------|------------|------------|------------|------------|
| NaNO₃       | 0.8        | 0.8        | 0.8        | 0.8        |
| NaF         | 1.25       | 1.25       | 1.25       | 1.25       |
| NaCl        | 0.4        | 0.8        | 1.6        | 3.2        |
| Na₂SO₄      | 1.2        | 1.2        | 1.2        | 1.2        |
| NH₄Cl       | 0.175      | 0.175      | 0.175      | 0.175      |

2.2 Characterization of Al-Si 12

| Element | Al | Si | Fe | Cu | Mn | Mg | Zn | Cr |
|---------|----|----|---|----|----|----|----|----|
|         | 86.7 | 12.7 | 0.123 | 0.12 | 0.0186 | 0.0011 | 0.0428 | 0.0123 |
The chemical composition of material that were used was obtained by OES test and was shown in table 2 above. From the table, it can be seen that the main composition of the material are aluminum and silicon.

The casting process starts with melting the material in electric furnace at temperature 800 °C. While waiting for the material to completely melt, the mold and tablet degasser were being prepared. The mold is coated with zircon and then preheated up to 350 °C in muffle furnace, while the tablet degasser is preheated at 100 °C in an oven. After the material melted completely, tablet degasser was inserted into the furnace and pressed by plunger until it dissolved completely inside the molten aluminum. The inserting time of degasser that is used are 3 minutes. Degassing process is needed to remove hydrogen gas that is trapped inside, also it was conducted to remove slag layer on the surface of moltenaluminum. After the degasser and molten aluminum completely mixed, it was poured into mold and porosity test cup at pouring temperature of 690 °C. Poured metal inside mold then undergo solidification step, while poured metal inside porosity cup was tested in vacuum condition with constant pressure of 100 mmHg for 315 seconds. The schematic design of the mold can be seen in figure 1 below.

The specimens for mechanical properties testing were obtained by using metal mold with design on figure 1. The tensile specimens can be obtained from t1, t2, and t3, while impact specimens can be obtained from i1, i2, and i3. The down sprue is located at the left side of the mold with diameter of 12 mm, and molten aluminum will flow into runner that is located at the bottom of the mold. The molten aluminum then will rise into tensile and impact area, and heat gas will be released from the mold via gas tunnel. After it solidified, the casting process was considered done, and the samples will be observed to investigate the mechanical properties of the casting products.

To characterize the mechanical properties of Al-Si12% as cast, 4 testing methods were chosen. It is tensile test, hardness test, impact test, and microstructure test. In order to get tensile test result, tensile
test was conducted by using GOTECH Al-7000 LA machine with JIS Z2241 standard. For hardness test, LCB 3100 LECO brinnel machine was used with 10 mm diameter of steel ball indenter and 1000 kgf force parameter, using ASTM E10 standard. Impact test was conducted by using Frank impact testing machine with charpy method, using ASTM E23 standard. Microstructure of Al-Si12% cast sample was obtained from SEM test, and it shows the phase that appears from casting process and also shows the number of porosity formed inside the molten aluminum.

3. Results and Discussion

3.1 Microstructure Observation and Phase Identification of Al-Si12

![Figure 2](image-url)

**Figure 2.** Macrostructure of Al-Si12% at various NaCl addition: (a) addition of 0.2%wt NaCl; (b) addition of 0.4%wt NaCl; (c) addition of 0.8%wt NaCl; (d) addition of 1.5%wt NaCl.

From figure 2 above, it can be seen that the number of porosities that formed in as-cast product with addition of NaCl in tablet degasser is very low. By comparing all of the macrostructure pictures from all of different NaCl addition in tablet degasser, it could be concluded that all of the results shows that by adding NaCl on tablet degasser, no matter how much the addition ratio is, it all have the same effect on reducing gas porosity that can be formed on as-cast products above.
Figure 3. Microstructure of Al-Si12 at various NaCl addition: (a) addition of 0.2\% wt NaCl; (b) addition of 0.4\% wt NaCl; (c) addition of 0.8\% wt NaCl; (d) addition of 1.5\% wt NaCl.

Al-Si alloys microstructure are affected by microstructural characteristics such as dendritic cell size and grain size. Al-Si will solidifies by a primary precipitation of aluminium dendrites (\(\alpha\)-Al) [4]. Based on microstructure result on figure 3, \(\alpha\)-Al area are pointed by black arrow, and the porosity that occurs in Al-Si12 casting products can be seen as black dots pointed by red arrow on picture C and D. It can be seen that most porosity are formed at casting product with higher NaCl addition, it is at addition of 0.8\% wt NaCl. At microstructure D, porosity are formed too, but the number of porosity that appears is lower than microstructure C. With low addition of NaCl inside tablet degasser composition, the number of porosity inside casting products are decreased, especially at addition of 0.2\% wt NaCl, where the number of porosity that appeared are very low, as a matter of fact it cannot be seen on the microstructure above.
3.2 Mechanical Properties of Al-Si12

![Tensile Strength Graph](image)

**Figure 4.** Effect of NaCl addition ratio on tensile strength of Al-Si12.

From figure 4 above, it can be seen that by adding more NaCl on tablet degasser composition, the tensile strength of Al-Si12 will increase at first from 189.14 MPa into 229.83 MPa, but after that the graphic will be showing a reducing number of tensile strength until the lowest tensile strength which is 174.67 MPa that belongs to addition of 3.2 kg NaCl into tablet degasser composition.

![Impact Strength Graph](image)

**Figure 5.** Effect of NaCl addition ratio on impact strength of Al-Si12.

Figure 5 shows the impact strength of each casting product with different NaCl ratio inside tablet degasser composition. From the result above, fluctuate graphic appeared. When increasing the number of NaCl inside tablet degasser, impact strength will decrease into 47 Joule, but after that it will increase again into 64.67 Joule. Highest addition of NaCl shows the lowest impact strength on Al-Si12, which is 32.3 Joule.
Figure 6. Effect of NaCl addition ratio on hardness of Al-Si12.

Figure 6 above represents the hardness of Al-Si12 casting product. From the result, it can be seen that all of the sample has a slightly similar hardness strength, except for sample with addition of 0.4% wt NaCl. It shows that 0.4% wt NaCl addition is not compatible for degassing method when the hardness of each casting product is compared.

3.3 Effect of Sodium Nitrate, Sodium Fluoride, and Sodium Chloride on Degassing

To remove dissolved hydrogen inside molten metal, tablet degassing is the simplest method that can be used in casting process. By holding the degasser with plunger inside molten aluminium, there will be a reaction between degassing particle and hydrogen gas that will cause binding process of hydrogen happened. The most common tablet degasser used is C2Cl6 tablet degasser, but because it can cause an environmental damage, it is prohibited to be used again.

In this research, NaF and NaNO3 were added as main composition of the tablet degasser to substitute the usage of C2Cl6. From equation (i) and (ii) below, it can be seen that each NaF and NaNO3 addition have a role in reducing the number of hydrogen gas trapped inside molten aluminium.

\[
\text{2 NaF} + \text{H}_2 \rightarrow \text{2 Na} + 2 \text{ HF} \quad (1)
\]

\[
\text{2 NaNO}_3 + \text{H}_2 \rightarrow \text{2 Na} + 2 \text{ HNO}_3 \quad (2)
\]

When adding tablet degasser into molten metal, nitrogen gases will be produced, and it will bound hydrogen gas, thus it will form gas bubbles and will float into the molten surface. It will be considered as a slag in casting and it needed to be removed immediately from the surface of molten aluminium.

The addition of NaCl have a purpose to see whether NaCl can be a substitute for NaF and NaNO3, because it has lower price and it was categorized as a salt flux just like NaF and NaNO3, so it will react with hydrogen gas with the same principle as NaF and NaNO3, as shown in equation 3 below.

\[
\text{2 NaCl} + \text{H}_2 \rightarrow \text{2 Na} + 2 \text{ HCl} \quad (3)
\]

NaCl will forms low-temperature eutectic (665°C), which is needed to improve the fluidity. Higher fluidity will cause the diameter of flux particle from tablet degasser to decrease, so it will increase the filtration efficiency of degasser particle inside molten metal [11,12].

4. Conclusion

Based on microstructure test and mechanical properties test that has been done in this research, it can be concluded that NaCl addition in sodium nitrate-sodium fluoride based degasser didn’t have any significant effect on reducing porosity in Al-Si12 casting product. On microstructure test, by adding more ratio of NaCl addition in tablet degasser composition, the number of porosity that appears are
increasing, and when comparing mechanical properties of Al-Si12 casting product at different NaCl addition, majorities of the result shows that the smallest addition of NaCl actually have the highest mechanical properties.

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