Effect of Sodium Nitrate-Sodium Fluoride Ratio as Degasser in Al-7Si-2Cu Casting Product

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Abstract. Effect of Sodium Nitrate-Sodium Fluoride Ratio as degasser in Al-7Si-2Cu Casting product has been investigated. Degassing is one of the methods used in the casting process to remove gases, such as hydrogen gases, in the molten metal. The most commonly used degassing method is by injecting an inert gas such as argon. In this experiment, a conventional degassing method with degasser-based sodium nitrate-sodium fluoride was used with changes in sodium nitrate to sodium fluoride ratio variables are 3:5, 4:4, and 5:3. The type of material used is Al-7Si-2Cu material with additional scrap. The material melted first at 800°C, then the degasser was added into the furnace and held for 3 minutes. High temperature was used to melt the material due to the solubility of hydrogen gases in liquid metal at high temperature is high. The molten metal then poured into the dies at approximately 690°C. The casting process results are then prepared for mechanical testing, such as tensile test, impact test, and hardness test, and microstructure testing. The results show that at the ratio of 1:1.5 (normal ratio), the porosity was lower (0.8 at average) and the mechanical strength was higher (1.2 at average).

Keywords: Casting. Degassing. Porosity. Sodium.

1. Introduction

Aluminum is one of the most used material because of it’s light weight and high ductility properties made it compatible to use in casting product. Unfortunately, pure aluminum has a low strength and some low mechanical properties, therefore it needs to be alloyed with other elements such as silicon and copper. The addition of alloying elements helps to increase its mechanical properties and adjust to the requirement needed on the final product. For example, addition of Si will improve the cast ability of the materials, lessen the possibility of hot tearing, lowering the thermal expansion coefficient, and improving its wear resistance[1]. Meanwhile, addition of Cu increases the strength, corrosion resistance, creep resistance, weld ability, machinability, and also make it possible to undergo a heat treatment process[2]. These alloys are commonly use in high speed rotating parts, pistons, structural aerospace components, fuel pumps, and other machine parts[1,3].
In order to produce a sound casting product using aluminum alloy, there are factors that needed to be considered such as melting temperature, pouring temperature, and turbulence during pouring. If one of those factors is neglected, it might cause some defects such as porosity in the final product. Porosity itself usually formed during solidification process in which the hydrogen gas was soluble and trapped within the molten metal. There are multiple studies which shows, that the presence of gas porosity in a casting product could significantly lower its mechanical properties such as impact toughness, elongation, and tensile strength[4,5].

To lower the amount of hydrogen gas soluble in the molten metal, there are several methods the industry can use. One of which commonly use method are fluxing and degassing method. Some research has been done using the fluxing method, especially using cover flux with NaCl and KCl as its main composition[6]. As to degassing method itself, there is a cheaper yet still compatible method which is using tablet degasser, mostly containing C2Cl6. In this study, the tablet degasser used is mixed degasser based sodium nitrate (NaNO3) and sodium fluoride (NaF) The expected result is by using this degasser, it will decrease the amount of porosity by binding the H2 gas out. In addition, the ideal composition of the degasser will also be studied by changing the ratio amount of NaNO3 and NaF used.

2. Materials and Methods

2.1 Making of NaNO3 and NaF Based Degasser

The mixed degasser used is containing 18%wt NaNO3 in powder forms, 40%wt NaF, and the other 42%wt consists of NaCl, NH4Cl(KCl), Na2SO4, and dye. All of them were then mixed with some water using a mixer machine. The stirring process then conducted for approximately 30 minutes to help homogenized the mixture. After that, the final mixture then processed and formed into the desirable shape, in this case it’s a cylindrical tablet shape, using a printing machine. Lastly, the tablet was put into the oven at 100°C for 1 hour to evaporate all of the moistures inside.

Some changes were made in order to conduct this study, those are the ratio amount of NaNO3 and NaF used. The ratio of sodium nitrate to sodium fluoride used are 3:5, 4:4, and 5:3.

2.2 Characterization of Al-7Si-2Cu

By using Optical Emission Spectroscopy (OES) material testing, the chemical composition of Al-7Si-2Cu were obtained and was shown in Table 1. It could be seen that the main component is Al with majority alloying element of Si and Cu.

|    | Al  | Si  | Fe  | Cu  | Mn  | Mg  | Zn  | Cr  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|
|    | 89.1| 7.06| 0.350| 2.30| 0.178| 0.246| 0.495| 0.0220|

The casting procedure started with melting the materials with additional scrap using an electric furnace at 800°C until its melted completely. While the materials were melting, the mold was coated with zircon and thinner mixture then preheated at 400°C for 30 minutes. The degasser itself also was preheated using a muffle furnace at 100°C for 1 hour to make sure there was no moisture left. After all the aluminum alloy melt completely, the preheated degasser then dipped into the furnace using a coated plunger. It needed approximately 3 minutes to do the degassing process until the degasser was completely dissolved. Next, the degassed molten metal was poured into the metal mold at 690°C and into the porosity testing cup. The schematic casting design can be seen in Fig. 1. The poured metal then underwent a solidification process,
while the one in the porosity testing cup was put into a vacuum condition at a constant pressure of 100mmHg for 315 seconds.

![Schematic of casting design. (a) Top View; (b) Front View; (c) Bottom View; (1) Down Sprue; (2) Runner; (3) Gas Tunnel; (t1, t2, t3, t4) Tensile Specimens; (i1, i2, i3) Impact Specimens.](image)

**Fig. 1.** Schematic of casting design. (a) Top View; (b) Front View; (c) Bottom View; (1) Down Sprue; (2) Runner; (3) Gas Tunnel; (t1, t2, t3, t4) Tensile Specimens; (i1, i2, i3) Impact Specimens.

The mechanical testing specimens were made using a metal mold design shown in Figure 1. The tensile specimens were obtained from the t1, t2, and t3, while the impact specimens were obtained form i1, i2, and i3. On the mold itself, the down sprue was placed on the far left side with the diameter of 12mm which can be seen as number 1, is where the molten metal was poured. The runner which is shown as number 2, help the molten metal flow and fill in all the specimen’s casting. Meanwhile the gas tunnels were placed on the right top side in order to remove gasses from within the metal mold, can be seen as number 3. After the casting process was finished, the specimen then prepared and observed to help to determine the mechanical properties of the casting products.

Tensile test, impact test, hardness test, and microstructure test were then conducted to help characterize the mechanical properties of Al-7Si-2Cu as cast. In order to do the tensile test, GOTECH AI-7000 LA 10 machine was used with the JIS Z2241 standard. The impact test was
conducted using frank impact testing machine, with the charpy method. For the hardness test, LCB3100 LECO brinnel machine with 10mm diameter of steel balls indenter was used with the force parameter of 1000 kgf.

For the porosity testing sample, after they were solidified in a vacuum condition, they were quenched in water to fasten the solidification of the remaining liquid metal in the center. The sample then cut in half, prepared, and observed to investigate the microstructure and the amount of porosity left in the solid casting products.

3. Results and Discussion

3.1 Mechanical Properties of Casting Al-7Si-2Cu with Degasser

![Graph showing the effect of NaNO₃ and NaF degasser on Tensile Strength of Al-7Si-2Cu](image)

Fig. 2. Effect of Ratio NaNO₃ and NaF degasser on Tensile Strength of Al-7Si-2Cu

Fig. 2. above shows the tensile test result according to the amount of degasser use in the casting process. The ratio of NaNO₃ and NaF also has an impact towards the tensile strength of Al-7Si-2Cu as cast. From the figure above, it could be seen that by using a 1:1.5 ratio of NaNO₃ to NaF, the highest tensile strength was obtained. Meanwhile, by using a 4:4 ratio, it resulted in the lowest tensile strength, even lower than the sample without using any degasser. Therefore, for the tensile test result, the degasser of 1:1.5 ratio works the best on removing the hydrogen gasses and increasing the tensile strength.
Fig. 3. Effect of Ratio NaNO₃ and NaF degasser on Impact Strength of Al-7Si-2Cu

Figure 3 represents the effect of NaNO₃ to NaF ratio on the impact strength of Al-7Si-2Cu as cast. The result is quite different from the tensile test result, because in here it was found that by using a 3:5 ratio of NaNO₃ to NaF, it has the highest impact strength. The lowest impact strength was obtained from the sample without using any degasser. It is true, since by not using any degasser at all, the amount of hydrogen gas soluble in the molten metal must be in a high number, therefore it’s decreasing the ability of the sample to withstand any sudden load.

Fig. 4. Effect of Ratio NaNO₃ and NaF degasser on Hardness of Al-7Si-2Cu

Figure 4 above shows the hardness test results of the Al-7Si-2Cu as cast without degasser and by using degasser. The highest hardness was obtained from a sample using a 1:1.5 NaNO₃ to NaF ratio with 97 BHN, it is the same as the tensile test result. The lowest hardness end result was obtained from the sample without using any degasser. In this case, without any help of degasser, the more the hydrogen gas are soluble within the molten metal, therefore the porosity is higher. A high amount of porosity could decrease the sample’s mechanical properties.
3.2 Microstructural Observation and Phase Identification of Al-7Si-2Cu

![Micrographs of Al-7Si-2Cu alloy](image)

**Fig 5.** Optical micrograph of as-cast alloy Al-7Si-2Cu with variation of NaNO₃:NaF ratio: (a) 0:0; (b) 1:1.5; (c) 3:5; (d) 4:4; and (e) 5:3.

It is already known that the mechanical properties of aluminum casting alloys depend on microstructural characteristics such as the grain size, dendritic cell size, and the size and morphology of the β-Al₅FeSi phase, as well as on the pores and inclusions[4]. Figure 5 represents the optical micrograph results for all the ratio. It could be seen from above there are some obvious black area which is the gas porosity trapped within the microstructure. Predominant phase of α-Aluminum in a dendritic form is shown by the white area. In this particular as-cast, the orientation and morphology of α-Aluminum is very disorderly. Accurate identification of the relatively coarse iron rich intermetallic phases commonly found in aluminum–silicon casting alloys is important, because some of these phases are associated with reduced mechanical properties[7]. In a very low concentration, Cu is soluble in α(Al) and is a
major constituent in the intermetallic phase CuAl₂ (θ-phase). After the precipitation of CuAl₂ at α-grain boundaries in Al-Si-xCu alloy, the microstructure becomes brittle and fails intergranularly[8] and this was proven by the fractograph of the impact test results.

Figure 6 shows the macrostructure appearance of Al-7Si-2Cu with all ratio. It could be seen that every cast result has small porosities from the gas entrapment, but the 1:1.5 ratio shows finer and more dispersed porosities. This result corresponds with the mechanical properties result that 1:1.5 ratio also has the highest value on tensile strength and hardness properties. By
resulting in finer and more dispersed porosities, this means that the mixed degasser works best in 1:1.5 ratio, that this is the effective ratio for the degasser to binds the H$_2$ gas out.

3.3 Effect of Sodium Nitrate and Sodium Fluoride Addition

The simplest method to remove dissolved hydrogen is to hold the metal for some time, allowing for some degassing. For a faster degassing process, it can be achieved by gas purging, the application of a vacuum, tableted flux degassing, or mechanical stirring[9]. The mixed degasser used in this study was mainly based on NaNO$_3$ and NaF. By equation (i) and (ii), it is believed that each of them has an effect regarding to the amount of soluble hydrogen gas.

\[
\begin{align*}
2 \text{NaNO}_3 + \text{H}_2 & \rightarrow 2 \text{Na} + 2 \text{HNO}_3 \quad \text{(i)} \\
2 \text{NaF} + \text{H}_2 & \rightarrow 2 \text{Na} + 2 \text{HF} \quad \text{(ii)}
\end{align*}
\]

Within the degasser used itself, all of the compound will later on produce nitrogen gas when it got submerged into the molten aluminum. Those nitrogen gasses then bound with the H$_2$ to form bubbles which resurfaced on the molten metal. These compound also has the ability to remove impurities within the molten metal and carry it to the surface which will make a disposal dross.

Sodium fluoride is actually a common ingredient to use, which formed a ternary eutectic with KCl and NaCl with a melting point of 607°C. A low melting point was needed in order to improve the fluidity[8]. Addition of NaF is studied to be increasing the hydrogen dissolution into the slag formed on the surface[10]. NaNO$_3$ and NaF are both salt fluxes that has a function to help wet the oxide inclusion. This resulted in enabling the removal of hydrogen that are trapped within the molten aluminum. By removing the H$_2$ gas, it is also reducing the amount of porosity that might get trapped during solidification. Thus, it could be resulting in a more sound casting products.

4. Conclusions

The use of a 1:1.5 ratio of NaNO$_3$:NaF degasser improved mechanical properties of Al-7Si-2Cu the best, due to the least amount of gas porosity based on the microstructure test results. Varying the amount of NaNO$_3$ and NaF has their own impact on the mechanical properties such as a higher impact strength but with a lower hardness, therefore it did not provide the best mechanical properties.

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6. References

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