Low pressure casting effect to tensile strength of aluminium

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Abstract. The air in the mould cavity is pushed out by liquid metal when the liquid metal entered mould cavity. In green sand-casting process, the air passes through the pores in the mould. Permanent mould doesn’t have pores and the air released from the mould cavity only through air outlet. Low pressure on mould cavity make liquid metal easier and faster filling the mould cavity, and make casting process can be done at lower temperature, the main focus of this research is about effect of pouring temperature on the low-pressure casting process to tensile strength and porosity of the aluminium. The casting process carried out at 750, 800 and 850°C. Aluminium smelting uses an electric furnace and the mould used is a metal mould with a pressure of 0.33 atm. The casting process on aluminium at low pressure (-0.33 atm) and at a temperature of 750 °C produces the highest tensile strength compared to aluminium casting at 800 and 850 °C. The increasing pouring temperature increasing porosity of aluminium is from 1.86% at 750 °C to 4.03% at 850 °C.

Keywords: Low pressure, casting, tensile strength, porosity

1. Introduction

The casting process is one of the oldest manufacturing processes discovered by human civilization[1][2]. The casting process technologies begins with metals that have a low melting point such as gold and silver and followed by metals and alloys with higher melting point such as bronze, brass, iron and steel.

The casting process is pouring molten metal into the moulding cavity, the entire moulding cavity filled with liquid metal before the metal solidifies [1,3]. Solidification process is affected by pouring temperature, type of mould material and mould temperature. High pouring temperature produces lower tensile strength metals compared with the metal poured at lower temperatures.

The difference of pouring temperature will make microstructure changed, higher pouring temperature will produced bigger grain size [4,5]. The temperature of moulding make cooling velocity on the liquid metal will be different, at high cooling rate the metal grain size will be small[3]. Reducing grain size will make tensile strength and hardness of the metals will increase [6-9].

The lower pressure in the mould cavity than the pressure of the outside air can accelerate velocity of the liquid metal l into the mould cavity, and can also prevent trapped air in the mould.
cavity. Permanent mould doesn’t have pores and the air released from the mould cavity only through air outlet. The higher velocity of the liquid metal reduces the risk of the metal freezing before the mould completely filled with molten metal also reduced. The suction force of the liquid metal also gives pressure on the liquid metal due to liquid metal velocity. This pressure can increase the strength of the metal due to microstructure. The microstructure changes also affected by pouring temperature [10,11]. This research is about the effect of pouring temperature on the low-pressure casting process on tensile strength and casting defects.

2. Method and material
The metal used in this research is aluminium alloy, the aluminium alloy composition can be seen in the Table 1

| Element | Composition (%) |
|---------|-----------------|
| Al      | 94.70           |
| Zn      | 1.39            |
| Fe      | 1.30            |
| Ca      | 0.79            |
| P       | 0.70            |
| Cu      | 0.69            |
| Ni      | 0.05            |
| Ti      | 0.04            |
| V       | 0.04            |
| Eu      | 0.04            |
| Cr      | 0.04            |

The aluminium was melted using an electric furnace (Figure 2). The capacity of the furnace is 300 grams aluminium or 2 kg of gold and the maximum working temperature 1050 °C. Aluminium was casted on a mould made of metal (mild steel), the temperature of the moulding was 150 °C as shown in Figure 1.

![Figure 1. Permanent Mould for Vacuum Casting](image-url)
The casting process was carried out at a pressure of 0.67 atm (at absolute pressure) or -0.33 atm at relative pressure. The pouring temperature were 750, 800, and 850 °C. The tensile strength of aluminium tested according to ASTM standard B557 and the porosity tested according to ASTM B311-17.

The dimension of the tensile test can be seen in Figure 3 and Table 2. The tensile test strain rate was done at 100.0 mm/minutes. Porosity test was conducted according to ASTM B311-17 as shown in Figure 4.

![Desktop Electric furnace](image)

**Figure 2. Desktop Electric furnace**

![Tensile Test Dimension](image)

**Figure 3. Tensile Test Dimension[12]**

| Symbol                          | Dimension (mm) |
|---------------------------------|----------------|
| G (Gage Length)                 | 90.0           |
| W (Width)                       | 6.1            |
| T (Thickness)                   | 6.0            |
| R (Radius of Fillet)            | 6.0            |
| L (Overall Length)              | 174.0          |
| A (Length of Reduced Section)   | 32.0           |
| B (Length of Grip Section)      | 30.0           |
| C (Width of Grip Section)       | 10.0           |

**Table 2. Aluminium Composition**
Figure 4. Porosity Test according to ASTM B311-17.[13]

3. Results and discussion
The results of the aluminium casting process can be seen in Figure 5. These specimens were poured at 750 °C, for each pouring temperature we make 3 specimens. On the surface of the test object there is still a defect (rough surface), for the tensile test the surface of the cast is flattened by a milling machine.

Figure 5. Aluminium Casting Specimen

Tensile test of the aluminium poured at 750 °C can be seen in Figure 6. The average tensile strength of the aluminium can be seen in Figure 7. The tensile strength of aluminium depends on the casting temperature, the highest tensile strength is aluminium which is poured at a temperature of 150 °C (130.67 MPa) and the lowest is aluminium pouring at 850 °C. The difference in the tensile strength of aluminium is due to differences in microstructure and defects or pores in the aluminium.
Figure 6. Tensile Strength Test Result for Aluminium Pouring at 750 °C

![Tensile Strength Test Result for Aluminium Pouring at 750 °C](image)

Figure 7. Effect of pouring temperature to tensile strength of Aluminium

![Effect of pouring temperature to tensile strength of Aluminium](image)

The microstructure of aluminium can be seen in Figure 8. The existing microstructure is a typical micro structure of casting results. The microstructure of aluminium poured at 850 °C has a finer grain size compared to aluminium poured at 800 °C. According to the Hall-Petch Law, what is poured at 800 °C should have a finer grain size because it has a higher tensile strength [14-16]. Aluminium resulted from cast at temperature 850 °C has a longer dendritic arm than aluminium casting at 800 °C. This dendritic arm also causes the strength of the aluminium decrease, the dendritic make the metal less strongest because dislocation stuck on the dendritic and make high density in this area [6,17]. High dislocation density makes the metal unable to accept large plastic strains so it breaks easily (its strength will decrease) [18,19].
Table 3. Porosity of Aluminium

| Pouring Temp (°C) | $\rho_{ap}$ (gr/cm$^3$) | $\rho_{th}$ (gr/cm$^3$) | Porosity (%) | Average Porosity (%) |
|-------------------|-------------------------|-------------------------|--------------|----------------------|
| 750               | 2.70                    | 2.748                   | 1.74         | 1.86                 |
|                   | 2.67                    | 2.748                   | 2.53         |                      |
|                   | 2.71                    | 2.748                   | 1.32         |                      |
| 800               | 2.67                    | 2.748                   | 2.60         | 3.07                 |
|                   | 2.65                    | 2.748                   | 3.25         |                      |
|                   | 2.65                    | 2.748                   | 3.38         |                      |
| 850               | 2.62                    | 2.748                   | 4.30         | 4.03                 |
|                   | 2.63                    | 2.748                   | 4.10         |                      |
|                   | 2.64                    | 2.748                   | 3.71         |                      |

Table 3 shows that the lowest porosity is found in aluminium casting at 750 °C, and the highest porosity is aluminium casting at 850 °C. The combination of microstructure (dendritic arm) and porosity makes the mechanical properties of aluminium change, the tensile strength of aluminium in casting at 800 and 850 °C as much as 44 MPa is much higher than between 740 and 800 °C which is only 6 MPa.

4. Conclusion
The casting process on aluminium at low pressure (-0.33 atm) and at a temperature of 750 °C produces the highest tensile strength compared to aluminium casting at 800 and 850 °C. The
increasing pouring temperature increasing porosity of aluminium is from 1.86% at 750 °C to 4.03% at 850°C.

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