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The effect of pouring temperature on the porosity of sand casted Al – Si alloy

Mochamad Arif Irfa'i[1*], Dzulkiflih[2], Diah Wulandari[3], Andita N.F Ganda[4] and Supardiyono[5]

[1, 3, 4] Department of Mechanical Engineering, State University of Surabaya, Surabaya, Indonesia
[2, 5] Department of Physics, State University of Surabaya, Surabaya, Indonesia

*Corresponding author: arifirfai@unesa.ac.id

Abstract. This study was conducted to know the effect of pouring temperature on the porosity of Al – Si alloy cast in the sand moulding. Al – Si alloy was melted using reverberator I. 706 furnace which was equipped with temperature controller. The liquefied Al – Si alloy was charged into the sand moulding with varied pouring temperature from 680ºC, 705ºC, 730ºC, 755ºC and 780ºC. The riser model moulding was used in this research. The porosity measurement was done by calculating the specimen weight at the open air and in the fluid (density calculation). The measurement would give the value of actual and theoretical density. Dye penetrant method was also used for porosity measurement at outer part of tested specimen. The average porosity of the sand moulded Al – Si alloy with the varied pouring temperature are 4.31%, 4.05%, 3.85%, 2.98% and 2.81% respectively. The porosity analysis using dye penetrant method showed that the gas porosity was shifting out to the outer part of specimen. In addition, the amount of porosity in the outer part tend to increase and harvest in the one point with the increase of pouring temperature.

Keywords: porosity, pouring temperature, sand moulding and Al – Si alloy

1. Introduction

Al – Si alloys are common used in the casting industry, due to their excellent fluidity filing the moulding. The casting product of Al – Si alloys are extensively applicate for automotive, manufacture component and other utensils [1]. In some cases, the casting product has a porosity defect that lead to the lessening of product quality. The porosity defect in the casting usually in the form of gas porosity, shrinkage porosity, hot tearing and cracks [2].

Pouring temperature is one of the reason which cause the porosity in casting. High pouring temperature can trigger the formation of shrinkage due to the different temperature of mould and liquefied metal in the die. Meanwhile, low pouring temperature cause the liquefied metal cannot fulfil the entire die which instigated by the premature cooling. The precise pouring temperature let the melted metal fill the die cavity completely. The fluidity of liquefied metal is also a factor that effect its ability placing the die cavity [2].

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There are two familiar techniques to measure the porosity of casting product, these are density calculation and dye penetrant method. Sand casting has been widely used in the casting industry because of the economic factor and its reusable properties [3]. Not required high cost production and the sand can be reused for the next casting process. Thus the study of the effect of pouring time on the porosity of Al – Si alloy casted using sand moulding is required to be explored.

2. Materials and Methods

The Al – Si alloy was used to build the test specimens for porosity measurements. Al – Si alloy was melted in the reverberator I.706 furnace. The melted metal was poured into sand mould with the varied temperature from 680°C, 705°C, 730°C, 755°C and 780°C. The sand for die was obtain from Kelud Mountain, Kediri, East Java, Indonesia [4]. And the pouring basin that was used in this research is riser model.

To determine the porosity of the cast samples, the test samples were cleaned from dust and other particles adhering to the surfaces. Porosity measurement was done by two methods, these are density calculation (pycnometry test) and dye penetrant method. The pycnometry test was conducted in αβϒ laboratory, Malang, East Java, by weighed the specimen in the open air. Then the specimens were soaked in the liquid and after a couple of minutes, it was lifted up slowly from the immersion liquid. The soaked specimen is later weighed while keeping it suspended in the air. The theoretical porosity then calculated using the following equation [5]:

$$\rho th = \frac{100}{\left(\frac{\%Al}{\rho Al}\right)+\left(\frac{\%Si}{\rho Si}\right)+\left(\frac{\%Cu}{\rho Cu}\right)+etc} \quad (1)$$

where ρth = theoretical density (gr/cm^3)
%Al = percentage of Al (%)
ρAl = density of Al (gr/cm^3)
%Si = percentage of Si (%)
ρSi = density of Si (gr/cm^3)

While the calculation of apparent density is based on this equation below:

$$\rho ap = \rho liquid\left(\frac{Ws}{Ws-Wsb}\right) \quad (2)$$

where ρap = apparent density (gr/cm^3)
ρliquid = liquid density (gr/cm^3)
Ws = weight in the air (gr)
Wsb = weight in the liquid (gr)

The percentage of porosity is calculated by comparing the value of apparent and theoretical density, as follow:

$$\%P = \left(1-\frac{\rho ap}{\rho th}\right) * 100\% \quad (3)$$

Where %P = percentage of porosity (%)
ρap = apparent density (gr/cm^3)
ρth = theoretical density (gr/cm^3)

Dye penetrant method is done by spreading penetrant to the tested area and let the specimen dry for 5 minutes, before it is spread with developer liquid. The developer liquid has a function for take the penetrant out from the tested area. The taken penetrant shows that there is a porosity inside specimen. Dye penetrant test is conducted either for top or side specimen.

3. Results and Discussions

3.1. Porosity measurement using density calculation

Theoretical density was obtained from composition measurement using Optical Emission Spectroscopy (OES). The result is shown in the Table 1.

Table 1. Composition measurement data

No	Element	Percentage (%)	Element density (gram/cm³)	Theoretical density (gram/cm³)
1	Al	84,5111	2,7	
2	Si	5,21	2,33	
3	Fe	0,501	2,69	
4	Cu	1,99	8,96	
5	Mn	0,334	7,21	
6	Mg	0,112	1,74	
7	Cr	0,0338	7,15	
8	Ni	0,0771	8,9	2,85
9	Zn	6,92	7,14	
10	Pb	0,229	11,34	
11	Sn	0,0186	7,36	
12	Ti	0,0334	4,51	
13	Ga	0,0164	5,9	
14	V	0,0136	6	

Theoretical density is analysed by this calculation below:

$$\rho th = \frac{100}{\left(\frac{\%Al}{\rho Al}\right)+\left(\frac{\%Si}{\rho Si}\right)+\left(\frac{\%Fe}{\rho Fe}\right)+\left(\frac{\%Cu}{\rho Cu}\right)+\left(\frac{\%Mn}{\rho Mn}\right)+\left(\frac{\%Mg}{\rho Mg}\right)+\left(\frac{\%Zn}{\rho Zn}\right)+\left(\frac{\%Pb}{\rho Pb}\right)+\left(\frac{\%V}{\rho V}\right)}$$

$$\rho th = \frac{100}{\left(\frac{84{,}51}{2{,}7}\right)+\left(\frac{5{,}21}{2{,}33}\right)+\left(\frac{0{,}501}{2{,}69}\right)+\left(\frac{1{,}99}{8{,}96}\right)+\left(\frac{0{,}334}{7{,}21}\right)+\left(\frac{0{,}112}{1{,}74}\right)+\left(\frac{6{,}92}{7{,}14}\right)+\left(\frac{0{,}229}{11{,}34}\right)+\left(\frac{0{,}014}{6}\right)}$$

$$\rho th = 2{,}85\ \mathrm{gram}/cm^3$$

The result of pycnometry test for 15 specimens to know their apparent density was shown on Table 2.

Tabel 2. Pycnometry result data

Room Temperature (˚C)	Specimen	Weight in the air (Ws)	Weight in the liquid (Wsb)
680	1	61	39
	2	60	37
	3	56	36
705	1	64	40
	2	60	38

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	3	59	38
730	1	68	43
	2	62	40
	3	59	37
755	1	63	40
	2	61	39
	3	64	41
780	1	61	39
	2	60	38
	3	59	38

The data which obtained from Table 2 was used for calculate the apparent density based on Equation 2. And the result was presented on Table 3.

Tabel 3 The percentage porosity from density calculation method

Number	Temperature		Theoretical densitiy (gr/cm^3)	Apparent density		Porosity (%)
	(˚C)	Spec.		(gr/cm^3)	average (gr/cm^3)	
1	680	1	2,85	2,772	2,727	4,31
		2	2,85	2,608		
		3	2,85	2,800		
2	705	1	2,85	2,666	2,734	4,05
		2	2,85	2,727		
		3	2,85	2,809		
3	730	1	2,85	2,720	2,740	3,85
		2	2,85	2,818		
		3	2,85	2,681		
4	755	1	2,85	2,739	2,764	2,98
		2	2,85	2,772		
		3	2,85	2,782		
5	780	1	2,85	2,772	2,769	2,81
		2	2,85	2,727		
		3	2,85	2,809		

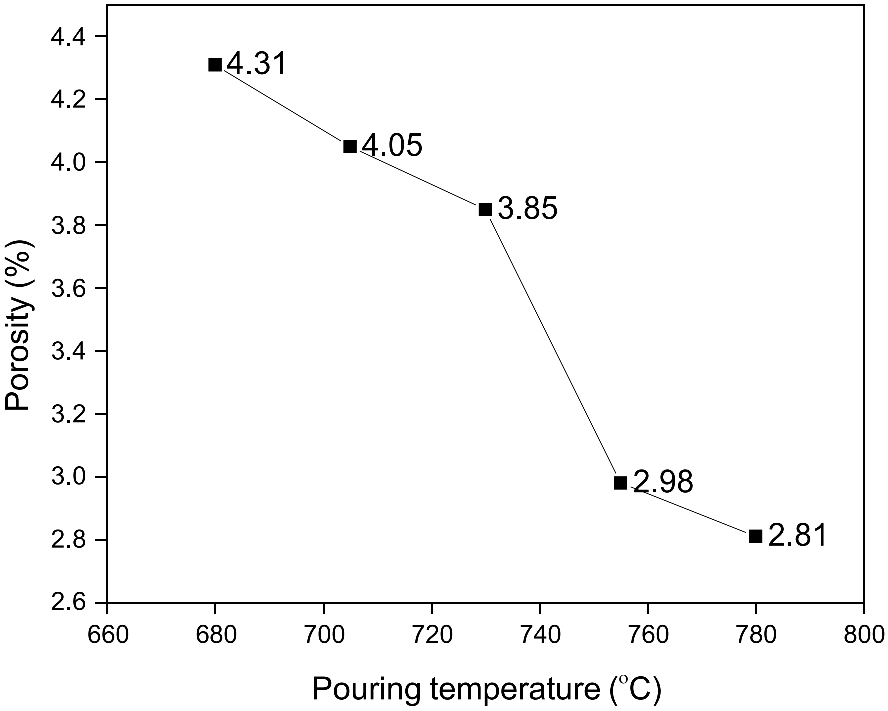


Figure 1. Graph of porosity measurement result

The data from Figure 1 shows that the percentage of porosity decrease within the increase of pouring temperature. The value of porosity percentage for pouring temperature of $680^{o}C$, $705^{o}C$, $730^{o}C$, $755^{o}C$ and $780^{o}C$ are 4.31%, 4.05%, 3.855, 2.98% and 2.81% respectively. The lowest porosity is occurred at $780^{o}C$ while the highest porosity is occurred at pouring temperature $680^{o}C$ (Figure 1). The difference between the highest and the lowest value of porosity is 1.51%. This phenomenon is happened, because the cooling time of melted metal is longer at high pouring temperature. So that the gaseous which are trapped inside melted metal, having a change to come out to the surface. It is proved in the Sabdo et al's research [6]. They studied the effect of pouring temperature on the recycle Al – Si alloy containing 88.75% of Al, 8.56% of Si and 0.775 of Fe using squeeze casting. The pouring temperature was varied from $660^{o}C$, $700^{o}C$ and $800^{o}C$. The result also shows that the increase of pouring temperature could create the low amount of porosity.

3.2. Porosity measurement using dye penetrant method

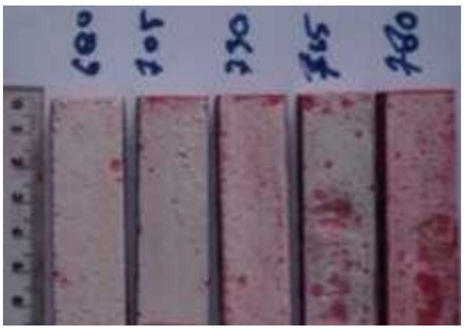
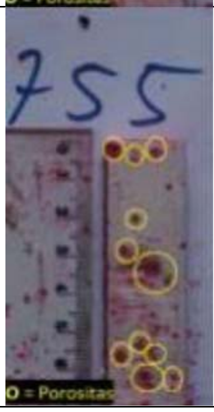


Figure 2. Digital photograph of tested specimen

Table 4 Dye penetrant test results

Pouring temperature (˚C)	Digital photograph	Description
680		Having a few porosities with the size of 1mm at some point on the surface.
705		Having a few porosities with the size less than 1mm spread not uniformly on the surface.
730		Having some porosities with the size of less than 1mm spread uniformly and a few porosities with 1 mm of size on the surface.
755		Having some porosities with the size of 1 mm and more than 1mm spread uniformly on the surface.

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780		Having some porosities with the size of 1 mm and more than 1mm which tend to gather at the one point on the surface.

As shown on the Table 4, the tested specimen just has a small amount of porosity on the surface with the size of 1 mm at pouring temperature 680°C. With the increase of pouring temperature, the amount of 1 mm porosity also increases. And the porosity tends to spread and get together on the surface of the specimen. These results are having the same evidence with the results which were obtained from density calculation test.

4. Conclusion

An investigation into the influence of pouring temperature on the porosity of Al – Si alloy has been undertaken. The result shows that the percentage of porosity decrease with the increase of pouring temperature. The value of porosity percentage for pouring temperature of 680°C, 705°C, 730°C, 755°C and 780°C are 4.31%, 4.05%, 3.855, 2.98% and 2.81% respectively. The lowest porosity is taken place at 780°C (2.81%) while the highest porosity is occurred at pouring temperature 680°C (4.31%). The difference between the highest and the lowest value of porosity is 1.51%.

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