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Improving the compact crucible furnace performance by adding fins in heating chamber

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Abstract. A crucible furnace is developed continuously to obtain appropriate furnace in support casting practice at VHS. This research aimed at improving performance of compact crucible furnace by modification the heating chamber. Fins were placed at inner side of compact crucible furnace wall. The furnace performance determined by increasing of temperature rate to melt 3 kg of aluminium. Descriptive analysis is used to describe performance of modified compact crucible furnace. The fins addition on the inside wall improves the compact crucible furnace performance. The temperature rate is increase as the fins inclination angle increase. Fins with inclination angle of 80⁰ could keep and maintain the temperature of heating chamber. Compact crucible furnace which added fin on the inside wall is able to melt 3 kg of aluminium in 35 minutes.

1. Introduction

Nowadays, most of ASEAN nations deal with the need of skilled labor [1]. This is directly related with vocational high school (VHS) as one of institution that provide skilled labor. The VHS should support the students in mastering competencies needed by stakeholders. One of that competence is casting process which substantial in product manufacturing. Regulation of Directorate General of Primary and Secondary Education of Indonesian Education and Culture Ministry number 06/D.DD5/KK/2018 dated 7 June 2018 about VHS expertise spectrum state that VHS student majoring in mechanical engineering should possess casting competency [2]. This indicate that is important for mechanical engineering of VHS student to learn casting process.

Furnace to melt metal is the main device in casting process. There are several kinds of furnace but the crucible furnace is the one that suitable for casting practice at VHS. The reason is the crucible furnace has simple construction thus easy to made, operate, maintain and low cost. The main features is the existence of crucible pot in the furnace on a support block. Charcoal, oil, or gas can be used as the energy source [3, 4, 5, 6]. There are two holes, one at the bottom side to supply heat from the energy source and the other at upper side to throw out combustion waste. Conventionally, the bottom hole is in the tangential direction. Thus, the heat will flow around crucible pot and then transferred to melt metal inside the pot.

The crucible furnace with liquid petroleum gas (LPG) as the energy source has been developed continuously [7, 8, 9, 10, 11]. The sustain development goal is to obtain appropriate furnace for VHS. The compact crucible furnace is the latest development at this time that appropriate for casting practice at VHS [9, 10]. It is being applied at several VHS. The advantages of compact crucible furnace are compact dimension (450x450x900 mm), simple construction, capable to melt 3 kg aluminum in 40-50

minutes, and the average gas consumption 2 kg. Unlike the conventional, the bottom hole in the compact crucible furnace placed exactly under the crucible pot.

Furthermore, the development also aimed at increasing the energy efficiency. Tanaka et.al. [12] had been developed a guide vane from cast refractory in the inner side wall of crucible furnace. The purposes is to make sure the heat flows around the crucible pot perfectly. The heat flow like passing the screw line so it will contact longer with the pot. This technique could improve the furnace efficiency. Another method introduced by Arianto et.al. [11]. Fin from steel welded to the pot so that form a screw line. Like Tanaka's method, the heat will follow the fin and flow perfectly around the pot. Moreover, the steel fin will catch the heat as it heated up. The heat then transferred conductively to melt the metal inside pot. Both development above was conduct for conventional crucible furnace.

This article will discuss an addition of steel fin in compact crucible furnace heating chamber to improve the performance. The concept is to hold the generated heat stay longer in the heating chamber. The heat caught by steel fin, which will have heated up thus the heating chamber temperature raise quicker and heat will remain longer.

2. Method

The compact crucible furnace uses high pressure stove to burn LPG. The crucible pot made from steel pipe with outside diameter 115 mm, thickness 8 mm, and height 195 mm. A 10 mm thick of steel plate welded to the bottom side of the pipe. Fins were made from 3 mm thick of steel as shown in Figure 1. The variation of inclination angle (α) of the fin are 0, 20, 40, 60, and 80 degrees. Fins placed in heating chamber as shown in Figure 2.



Figure 1. Fin from steel

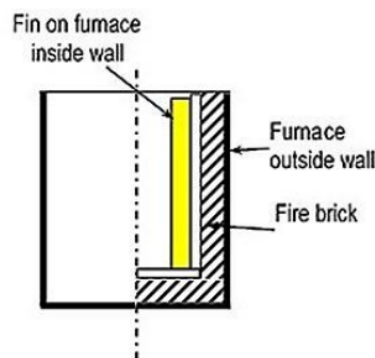


Figure 2. Fin placement in heating chamber

The experimental procedure was done with steps as follows: (1) Weighing 3 kg of aluminium, melted, and let it solidify in the crucible pot; (2) Placed fins onto the inner side wall of compact crucible furnace and warmed up the heating chamber up to 70-80 °C; (3) Weighing the initial weight of LPG using digital scale Slimline Electronic Scale TIF 9010A; (3) Heating the aluminium that had been prepared in the first step until it melt; (4) The temperature changes of aluminium, fins and compact crucible furnace inside wall were recorded every 5 minutes using infrared thermometer Krisbow KW06-409 until the aluminium melted. Repeat the steps above for other fins variation.

3. Result and Discussion

The compact crucible furnace with high pressure stove shown in Figure 3. The high pressure stove is placed at the bottom side thus the compact shape of the furnace achieved. The furnace made from rolled and welded of 2 mm thickness of steel plate [10]. The inner side furnace isolated by firebrick that installed using fire clay. The furnace also equipped with extended and deflected exhaust pipe as economizer [8]. The compact crucible furnace supported by a frame made from L profile steel of 40x40x3 mm.

The fin shape has design as shown in Figure 4. It welded on a steel plate that has two hooks. It has incline portion to directing the flow of heat in heating chamber of furnace. The incline portion is on lower side exactly at the crucible pot position. Inclination of fin were varying of 0, 20, 40, 60, and 80 degrees. The fins arranged in the heating chamber as shown in Figure 4. It arranged encircling the crucible pot. Fins deflect flow of the heat from stove to extend the path of the flow of heat so the heat will held longer in the heating chamber. Thus, when fins heating up as hit by flow of heat from stove below, the heating chamber temperature increase faster. Convection heat transfer occurs on the surface of crucible pot wall and then heat transferred through wall of crucible pot conductionally to the aluminium.



Figure 3. Compact crucible furnace with economizer

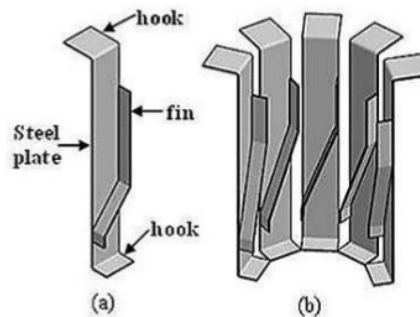


Figure 4. (a) Fin design; (b) Fin arrangement



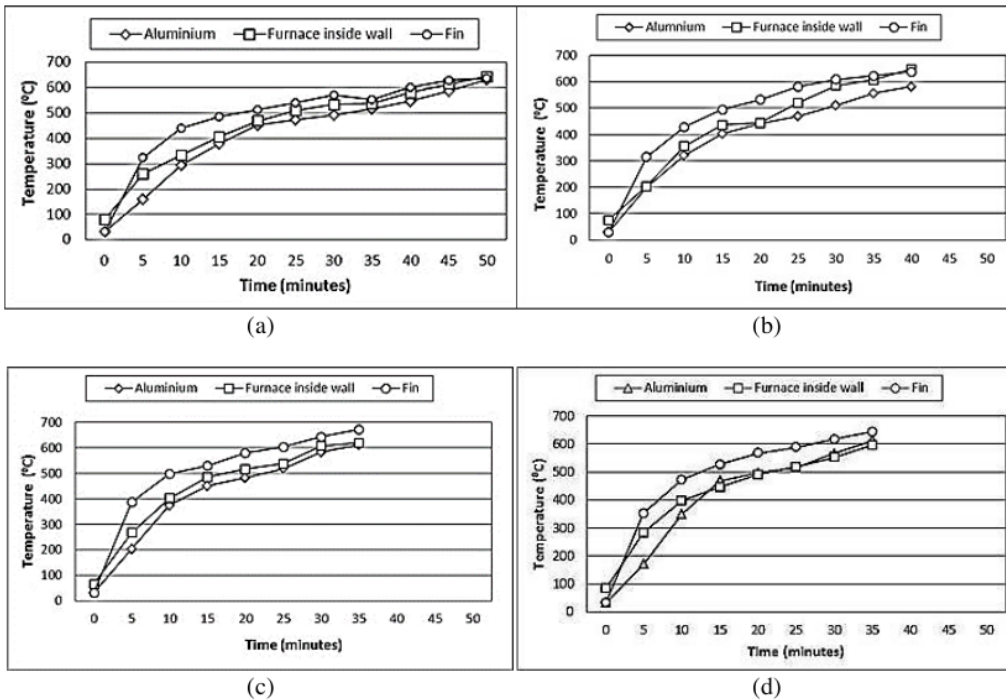
Figure 5. Fins placement in heating chamber

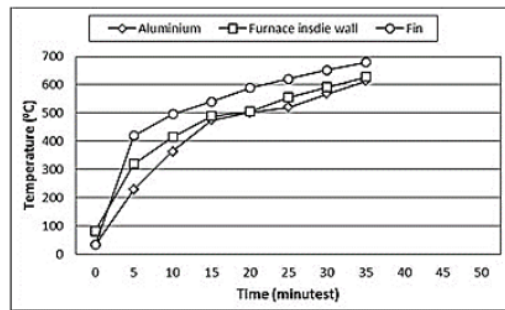


Figure 6. Inclined portion of fins in red color

Figure 5 shows the placement of fins in the heating chamber. Fins were placed encircling pot on the compact crucible furnace hooked at inside wall. Figure 6 shows heating process in the furnace heating chamber. It can be seen that at the section where fins lie, the heating chamber more red in color. Further observation indicates that red color is concentrated at where fins inclined. It is proven that fins also isolating heat to stay longer around pot. Thus, heat around inclined portion of fins increase pot temperature faster. This condition occurs on all of variation of fin angle inclination.

Fins addition on heating chamber wall could improve compact crucible furnace performance as shown in Figure 7. It can be seen that temperature of fins increases faster compare to wall of the inside furnace and aluminium in the pot. This indicates that fins of steel absorb the heat. The heat then radiates to crucible pot thus both pot and aluminium inside pot achieve almost equal temperature. Furnace with inclination angle of fins of 0 degree able to achieve 650 °C in 50 minutes. This result similar to furnace development conduct by Arianto, et.al [10]. However, figure 7 shows that addition of fins will affecting the performance of compact crucible furnace. The increasing of inclination angle would give faster temperature increasing. The variable of inclination angle does not relate with variable of fin gap, which differ with study conduct, by Arianto et, al [10]. However, inclination angle more than 90 degree will causing flow of the heat turn back, which can cause damage to the stove. Furthermore, the curve slope is increase rapidly at first 5-10 minutes by the increasing of inclination angle of fin. It can be observed from Figure 7. This due to the ability of fin in retarding the heat flow and explain how pot temperature rise faster.



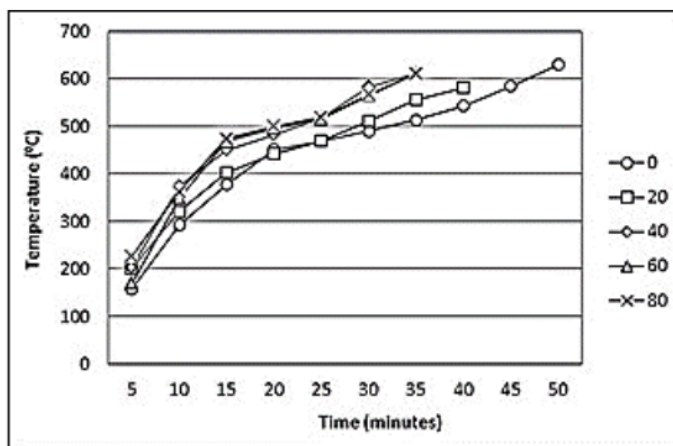


(e)

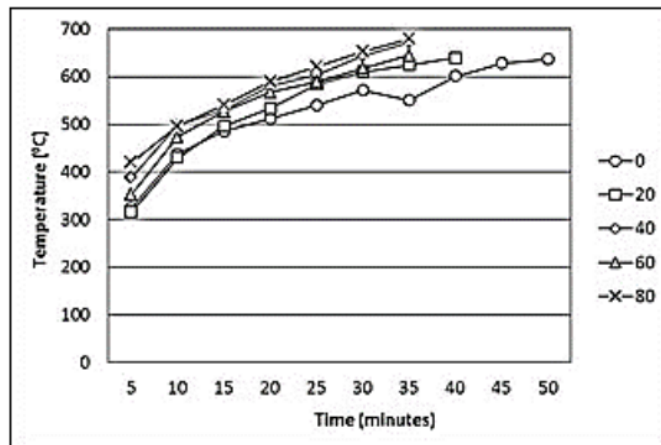
Figure 7. Effect of fin addition on performance of compact crucible furnace.
 Fin inclination angle: (a) 0°; (b) 20°; (c) 40°; (d) 60°; (e) 80°.

At Figure 7e is observed that fin reach 680 °C in 35 minutes as well as the increasing of aluminium temperature. This indicate that flow of heat from below furnace restrained at inclined portion of fin which heat up quickly and then spread around crucible pot. After that, heat transferred by crucible pot wall of steel to aluminium.

Figure 8a shows similar tendency of temperature changes of aluminium on fin inclination angle of 40°, 60°, and 80°. This due to the same heat transfer mechanism. However, slightly different tendency shown at Figure 8b. Heat-increasing rate on fin inclination angle of 80° is faster since heat restrained longer. Heat flow from below extremely deflect on fin inclination angle of 80°. Thus, fin heated up quicker. Heat received by crucible pot and aluminium occur through conduction mechanism thus aluminium heat increasing rate is not too affected by fin inclination. Contrary with spiral finned crucible pot [11], the fin inclination angle and pot diameter determine fin pitch thus, there is optimum condition. In this study, fin hooked at inside wall of the compact crucible furnace so the crucible pot diameter is not take effect. It is been imply that fin inclination angle of 80° able to isolating heat at inclined portion better. This means, it will maintain temperature at this area when stove turned off and pouring process conducted.



(a)



(b)

Figure 8. Effect of fin inclination angle on heat increasing rate of: (a) fin; (b) aluminium

However, there is an obstacle in this innovation. The compact crucible furnace has narrow heating chamber that limiting the use of crucible pot with wide diameter. Thus, when molten aluminium ready to poured, the crucible pot should be taking out because ladle cannot be use to pick up molten aluminium. Fin addition on inner sidewall of compact crucible furnace causes difficulty since space of heating chamber become narrower. Likewise, when crucible pot will put in again into heating chamber for next melting process. Further innovation must be conduct to improve the performance of compact crucible furnace with better operating. Heat requirements for melting aluminium is also not calculated. This is because the study purpose is only to determine the effect of fin additions and inclination angle on performance of compact crucible furnace. However, the heat requirement should be calculated to determine the furnace efficiency as fins added.

4. Conclusion

The using of inclined fin could improve performance of compact crucible furnace. Increasing of fin inclination angle would raise the heat-increasing rate in heating chamber. Fin with inclination angle of 80° could restrained temperature of heating chamber and able to melt 3 kg of aluminium in 35 minutes. However, hooked fin at inside wall of crucible furnace causing difficulty in pouring process.

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