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Effect of Mold Material on Shrinkage of Investment Casting Wax Pattern

Dedy Masnur [a], Harrianda Hudaya [a], Putri Nawangsari [a], and Warman Fatra [a,*]

[a)] *Mechanical Engineering Department, Faculty of Engineering, Universitas Riau, Indonesia*

*Corresponding author: warman.fatra@lecturer.unri.ac.id

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ABSTRACT

Various attempts have been made to substitute metal as the wax pattern mold material due to manufacturing costs and time-consumption. This research investigates the linear and volume shrinkage on the wax pattern of gypsum, silicone rubber, and epoxy resin as alternative materials to metal molds. A nylon master pattern was made by machining. The master pattern size was set as a reference for dimensional comparison with the cast wax pattern. Wax pattern molds were created using the master pattern, namely gypsum, silicone rubber, and epoxy resin. Paraffin wax was heated up to 55˚C in metal, then poured into each wax pattern mold. The length, radius, inlet, and outlet diameter were measured using a profile projector, then the linear shrinkage was calculated. The volume shrinkage was obtained through the sample weighing. The results show that silicone rubber has the lowest linear shrinkage of any sample in contrast to its volume shrinkage.

KEYWORDS: *wax pattern, linear shrinkage, volumetric shrinkage, investment casting, mold material.*

NOMENCLATURE

S_a	Top sprue length
t	Average pattern thickness
T_s	Sprue height
S_b	Bottom sprue length
A_b	Bottom sprue area
A_g	Gate area
l_m	Master pattern dimension
l_s	Sample dimension
V_m	Master pattern volume and
V_s	Sample volume

1.0 INTRODUCTION

Investment casting is a casting method using expandable wax to cast complicated precision parts and jewelry. The process name is based on the pattern surrounded or invested by a ceramic coat [1]. This method has been widely applied in industries ranging from the health industries, agriculture, textiles, weapons, electronics, automotive and electrical components [2].

One of the stages in investment casting is wax pattern making. The quality of the wax pattern depends on the quality of the cast products. There are four wax types: paraffin, bee, montan, and china wax. Those waxes were mixed in a specific combination and cast in a mild steel mold. The cast product has the linear shrinkage and volumetric shrinkage wax pattern percentages of 0.98% and 2.53%, respectively [3]. However, metal as a material for wax patterns mold is expensive and time-consuming.

Many materials as an alternative have been studied to substitute metal as a wax pattern mold, namely: epoxy resin, silicone rubber, and gypsum [4–6]. The epoxy resin had an 80-90% successful rate of substituting metal as a wax pattern mold at 55 to 70 °C and injection times of 7.5 s and 22.5 s [7]. Kerem and Cigdem, 2012 reported that the thermal expansion of mold materials influences dimensional changes of the casting products [8]. Kusyairi et al. 2019 studied the dimensional changes in casting products with wax molds from Portland cement and silicone rubber. They concluded that silicone rubber is more precise than Portland cement [9]. There are alternative materials to substitute metal as a wax pattern mold.

This research investigates gypsum, silicone rubber, and epoxy resin as alternative materials to substitute metal molds by comparing the linear and volume shrinkage on the wax pattern.

2.0 METHODOLOGY

2.1 Materials

There were three types of mold materials in this research: A Plus gypsum casting, epoxy resin with hardener, and silicone rubber RTV 683. The mold pattern material was nylon rods

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with 100 mm in diameter and 75 mm in height. The casting pattern material was Paraffin wax. Margarine was lubricated on the pattern and mold surfaces to ease the pattern removal from the mold.

2.2 Method

The mold pattern was designed carefully; therefore, it is sufficient to indicate linear shrinkage. There were several dimensions observed, beginning with length (L1 and L2), radius (R1 and R2), inlet, and outlet diameter (Figure 1). The master pattern and gating system are made from nylon through machining. The sizes of the gating system were calculated using the following equations [12]:

$$S_a = 3.5 \text{ x } t \quad (1)$$

$$T_s = 6 \text{ x } S_a \quad (2)$$

$$S_b = 2(0.5\, S_a - ((T_s \text{ x } \cos 0.5°)/100)) \quad (3)$$

$$A_b = S_b^2 \quad (4)$$

$$A_g = A_b \quad (5)$$

The calculation results of the gating system are shown in Figure 2a. The master pattern was attached to the gating (Figure 2b).

The master pattern was used to create molds in three types of material. For the gypsum mold, the master pattern was placed in an acrylic box and lubricated with margarine (Figure 3a). Next, the slurry gypsum was poured into the mold until it the half-drowned with slurry gypsum (Figure 3b). Similar steps were carried out to manufacture another half (Figure 3c, d). The final mold is shown in Figure 3e. The similar steps were applied to make the silicone rubber and epoxy resin mold

Paraffin wax was heated in a metal cup, and a digital thermometer monitored its temperature. When the temperature reached 55˚C, the paraffin wax was poured into the gypsum mold and allowed to cool. Next, the sample was ejected from the mold. Three samples were collected for each mold material.

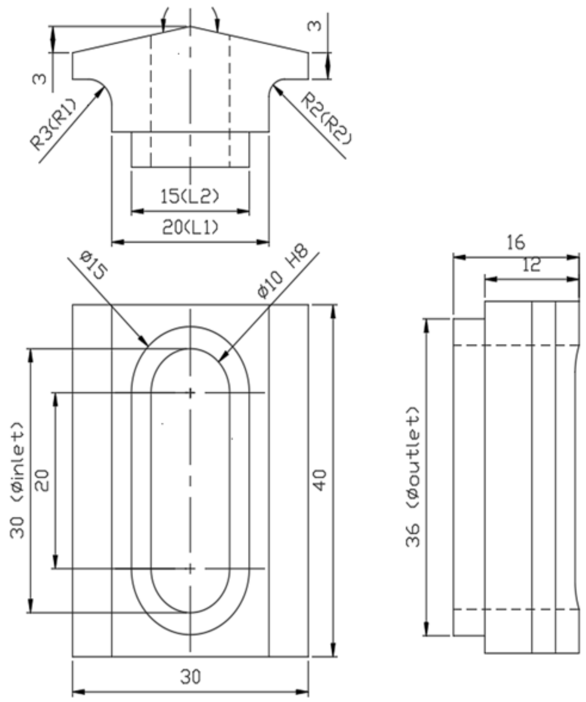
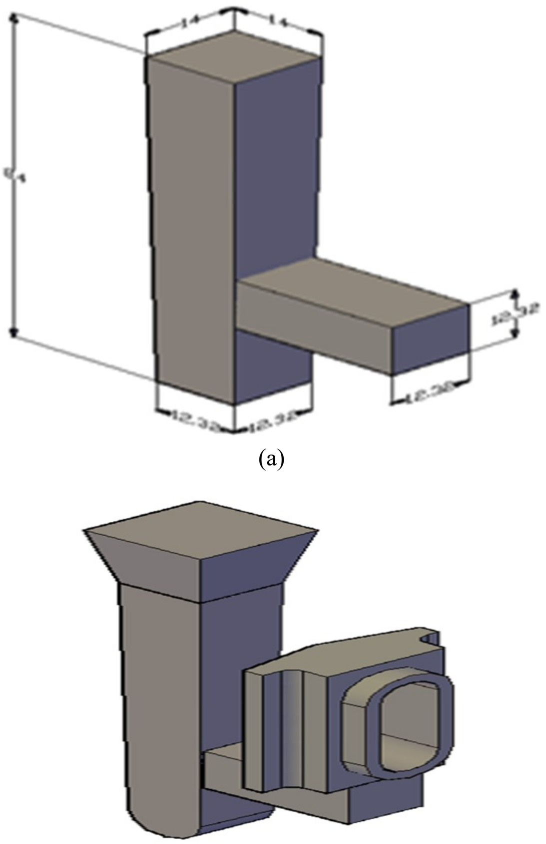


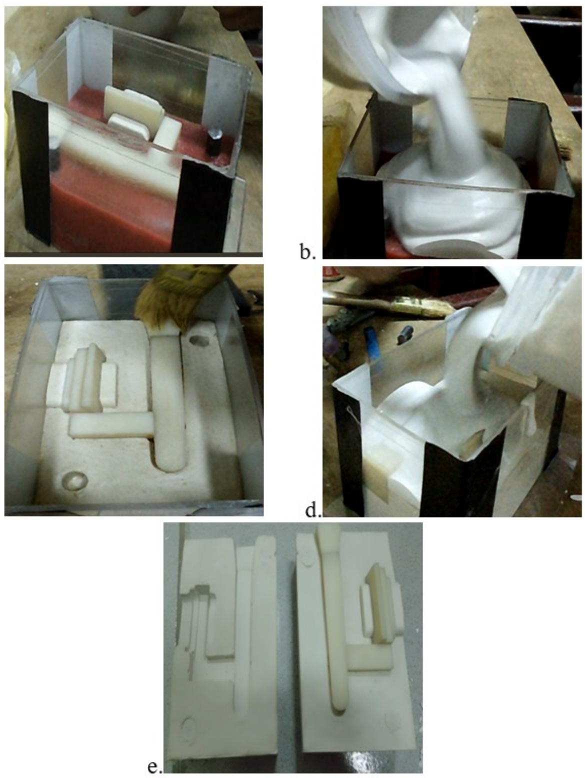
Figure 1: Mold pattern



(a)

(b)

Figure 2: (a) Gating design, (b) Assembly of the gating system



a. b. c. d. e.

Figure 3: Steps in gypsum mold making

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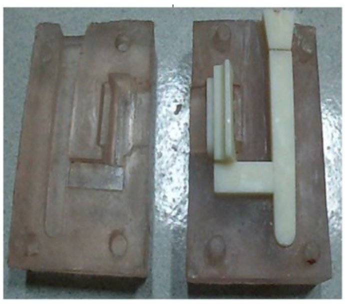
(a)



(b)

Figure 4: (a) Silicone rubber mold, (b) epoxy resin mold

The profile projector was used to measure L1, L2, R1, R2, inlet, and outlet diameters with a 10x magnification lens and an accuracy of 0.01 mm. The linear shrinkage was calculated with equation 1. By subtracting the observed master pattern dimension and the casted sample; they were divided by the master pattern dimension (equation 6).

$$\text{Linear shrinkage} = (l_m - l_s)/l_m \times 100\% \quad (6)$$

The samples were weighed on a digital balance with 0.01 gr accuracy. The volume shrinkage was calculated using equation 7.

$$\text{Volume shrinkage} = (V_m - V_s)/V_m) \times 100\% \quad (7)$$

3.0 RESULT AND DISCUSSION

The casted sample is shown in Figure 5. The linear shrinkage on the observed dimension (the outlet diameter, inlet diameter, length 1, length 2, radius 1, and radius 2) is presented in Figure 6.

Figure 5: Casted sample

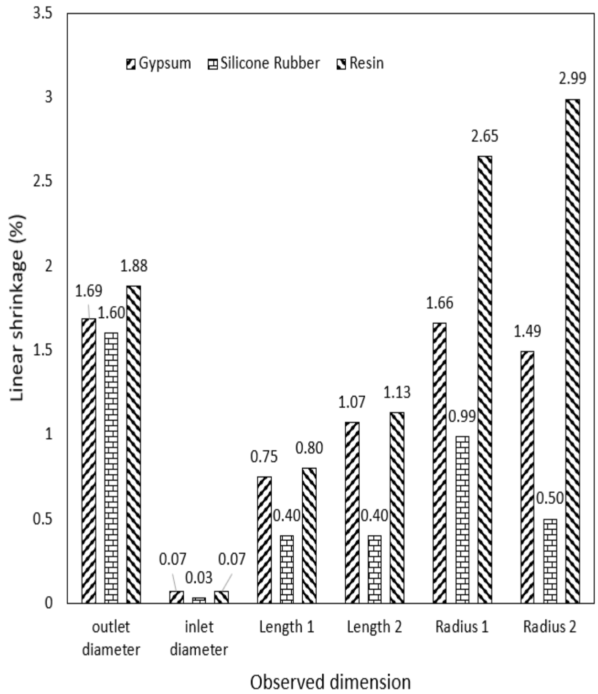


Figure 6: Linear shrinkage at observed dimensions

The linear shrinkage of the wax pattern was minimizing in the silicone rubber mold at all observed dimensions, while the maximum percentage was in the epoxy resin mold. The linear shrinkage of wax pattern in the silicone rubber at the outlet diameter, inlet diameter, L1, L2, R1, and R2 were as follows 1.6, 0.03, 0.4, 0.4, .99, and 0.5. The linear shrinkage of wax pattern in the epoxy resin mold at the outlet diameter, inlet diameter, L1, L2, R1, and R2 were 1.88, 0.07, 0.8, 1.13, 2.65, and 2.99 (Figure 6).

The large shrinkage percentage occurred at the outlet diameter and R1 in the silicone rubber mold as well as in the epoxy resin mold. Moreover, in the epoxy resin mold, a large shrinkage was found at the R1 and R2. Linear shrinkage was affected by the materials. It was seen from the variation of the linear shrinkage in all observed dimensions. The largest shrinkage occurs in the epoxy resin mold, while the smallest was in the silicone rubber. Mold materials have a thermal conductivity, which allows them to transfer heat. Gypsum, epoxy resin, and silicone rubber have thermal conductivity of 0.25 [5], 0.35 [10], and 0.2 W/m.K [11].

The heat from the wax pattern was transferred to the surroundings by the mold material during the cooling process. The transfer stops if the equilibrium condition was achieved. The heat transfer on materials is affected by their thermal conductivity (k), medium thickness (Δx), and area (A) [13]. The value of k determines the heat conduction flux (Q); a small k value yields a small heat conduction flux and vice versa. The heat conduction flux affects the solidification process of wax patterns. The wax solidifies from the wall to the center. Mold materials with large k transfer more heat than the material with the lower one. Less thermal conductivity was expected to provide uniform wax solidification between the core and wax surface.

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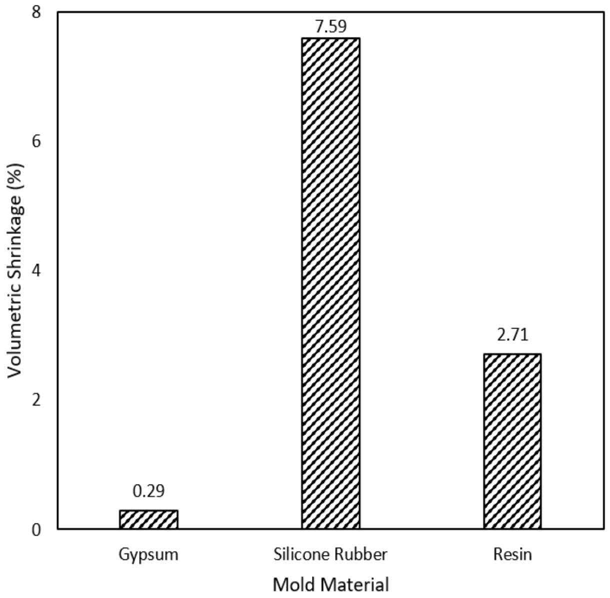

Figure 7: Volumetric shrinkage

The liquid candle creates the first solid on the interface of liquid wax and mold. The solid wax molecules bond with the liquid wax molecules in the middle until solidification was completed. The time required to complete this process relies on the amount of heat transfer.

(a)

(b)

(c)

Figure 8: (a) Porosity in gypsum mold, (b) silicone rubber mold and (c) epoxy resin mold

The mold with low thermal conductivity can keep the liquid wax temperature falling. It lengthens the solidification process; therefore, it allowed the slurry wax on the spruce to fill the voids in the mold cavity because of the Marangoni effect [14]. Therefore, it was found that the minimum shrinkage in all observed dimension, and large shrinkage was seen on the epoxy resin mold. This result was lined by Wahyudi, 2015 who also found a large shrinkage on the epoxy resin material [15].

The average volumetric shrinkage in gypsum, silicone rubber, and epoxy resin is presented in Figure 7. The lowest volume shrinkage of all samples was 0.29% on gypsum mold, while the highest was 7.59 on silicone rubber. This condition was due to the permeability of the mold material. Permeability was the mold's ability to transmit the air from the cavities to the environment during the filling process [16]. High mold permeability reduced gas porosity defects in wax patterns and vice versa. Gas porosities occurring were as a result of trapping gas in the mold cavities. Gypsum mold has more porous than other samples; therefore, only a small pore was found in this mold Figure 8a. Epoxy resin and silicone rubber molds have fewer pores; as a consequence it holds a large amount of air in the mold cavity, resulting in a large porosity hole, as seen in Figure (b) and (c).

4.0 CONCLUSION

Silicone rubber has the lowest linear shrinkage percentage of samples in all observed dimensions except inlet diameter (R1). In contrast, it has the highest volumetric shrinkage at 7.59%. Volumetric shrinkage increases with the thermal conductivity.

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