Differences in precision of wax molds made of portland cement and silicone rubber in investment casting process for economic efficacy

I Kusyairi1*, M A Choiron2, H M Himawan1 and Y S Irawan2
1Mechatronic Engineering, Politeknik Kota Malang, POLTEKOM, Malang, Indonesia.
2Mechanical Engineering, Brawijaya University, UB, Malang, Indonesia.

E-mail: kusyairi1408@gmail.com

Abstract—The investment casting method has several advantages, namely the ability to mold complex objects, create products smooth surface and high precision. This is closely related to the wax pattern used, if the wax already has a precision geometry with a precise shrinkage estimation during the casting process, the product will be in accordance with the plan, and vice versa. This study compares the level of roughness and precision of wax molds made of Portland cement and Silicon Rubber. The first step was making a product design with CAD, the product pattern to be made was the origami crash box with a thickness of 3 mm. The second step, converting the CAD file to .stp/.step then printing the design with 3D Printing. The third step, duplicating the 3D printing results with Portland cement material on the first mold and silicone rubber on the second mold. The first mold was designed with the assembly method, the assembly will be carried out after the first part and the second part have been finished. The fourth step was pouring wax that has been mixed with dammar gum (Shorea javanica), onto each gate that has been designed. The study found that the percentage difference between design and cement was 14.7% while the difference between design and RTV Silicon Rubber was 2.7%. This proves that RTV Silicon Rubber can form more precise patterns than cement. RTV Silicon Rubber mold is able to form complex patterns. The surface roughness adjusts to the imitated pattern, if the pattern is smooth then the surface produced by RTV Silicon Rubber mold is smooth, and vice versa.

1. Introduction
The investment casting method is the most widely used method for making parts that require high precision. Investment casting is able to make complex, thin and smooth structures. The investment casting method has several stages, (1) making wax molds, generally using metal, (2) pouring heated wax onto wax molds, can be poured manually or by injection method, (3) making ceramic slurry, in this process, the powder used for ceramic slurry was divided into two, namely fine powder and coarse powder (4) Coating ceramic slurry, wax pattern was coated with ceramic slurry (5) dewaxing, heating the coated wax pattern, this stage was carried out so that the wax came out of the mold (6) Pouring, casting metal into molds.

To achieve the desired precision, various factors need to be considered in the six processes, starting from making wax dies to finishing. A lot of research has been done on the investment casting method, proving that the investment casting method can be used in molding complex objects and producing desired thicknesses [1,2], research also leads to pouring methods, which influence the quality of wax patterns. Therefore, researchers designed a low-pressure injection device to get the maximum wax pattern [3].
Research on investment casting method also leads to gate design, so that the incoming liquid can fill every space [4,5], on the issue of smoothness, research on investment casting method develops the composition of ceramic slurry, adds some refractory materials that have a certain smoothness that can produce desired smooth surface [6,7], research on wax pouring temperature concluded that, the high pouring temperature gave more shrinkage, the casting of wax onto the mold was carried out between the pour temperatures of 50º - 60 ºC. Apart from the casting temperature, shrinkage also happens due to the geometry factor [8].

![Figure 1. Wax mold made of cement.](image)

Making wax molds is generally done with metal-based molds, the results obtained from metal molds are able to precisely mold complicated patterns by including 2% wax shrinkage value from the pattern design. Since the costs incurred are too high for some circles, there are several solutions to overcome it, one of them is the development of RTV Silicon Rubber mold [9,10,11] which was predicted to form complicated patterns. Household-scale industries also using cement as a wax mold, as shown in Figure 1, this research will compare two alternative substitutes for metal molds, in the form of precision comparison between cement mold and RTV Silicon Rubber mold.

2. Method
2.1. Cad design
The first step was to design the pattern for metal casting. In this research, the origami Crash Box design which was split into two parts was chosen, as shown in Figure 2 [12]. With a thickness of 3 mm, the wall of the origami crash box consisted of 3 indentations. The challenge in the process of pouring wax and metal was to ensure that the liquid flows, passes, and fills the angles and indentations of the origami crash box.

![Figure 2. Origami crash box.](image)
2.2. Design printing
After the modeling process in CAD software is complete, then CAD files are converted into .stp / .step files, and run on 3D Printing machines that are operated with Cura software. The material made to print the parts was PLA filament with a diameter of 1.75 mm, the temperature of 240°C, nozzle size of 0.4 mm, speed of 30 mm/s, processing for 17 hours 14 minutes. Modeling the images shown in Figure 3a work using buffer (blue) and object in red. The results of 3D printing work as shown in Figure 3b, the buffer is still attached to the part and needs to be finished. Figure 3c is the result of finishing and the surface is still not smooth.

![Figure 3a. 3D Printing modelling.](image)
![Figure 3b. Result of 3D printing.](image)
![Figure 3c. 3D Printing process.](image)

2.3. Mold making
In making a wax mold from cement, the result of 3D Printing is pressed with cement from the front and back. After the cement dries, the next process is to smooth the mold surface. The result of the cement mold processing was divided into 3 parts as shown in Figure 4a. Figure 4b is the picture of mold parts put together, consisting of 2 (two) gates which are the entry points for the wax.

As for the manufacture of the wax mold with RTV Silicon Rubber by mixing RTV Silicon Rubber with Hardener. The stirring process then followed by pressing the parts into the mixture, let stand until the liquid hardens. The mixture hardening duration depends on the type of hardener. The results of RTV Silicon Rubber mold can be seen in Figure 5a, which consists of two parts. The Silicon Rubber mold design is supported by cement so that Silicon Rubber does not change shape like in Figure 5b.

![Figure 4a. Divided into 3 Parts.](image)
![Figure 4b. Cement mold parts put together.](image)

![Figure 5a. Outer and inner molds.](image)
![Figure 5b. Mold parts put together.](image)
2.4. Pouring
Paraffin wax, which has the chemical formula $C_nH_{2n+2}$, will harden at room temperature and will melt at a temperature of around 37 °C (99 °F) [13] was used in this research. Paraffin, which has been cut into pieces, then mixed with dammar gum in a heated furnace. The ratio of paraffin wax to dammar gum was 1:4, as shown in Figure 6a. Before being put into the furnace, dammar gum was ground into a powder to avoid the explosion that might happen if it is burned in the form of a lump. The combustion process took up to 120 minutes until the paraffin and dammar gum was mixed and turned brown, as shown in Figure 6b. Figure 6c is the picture of solid paraffin. The pouring temperature was in the range of 50°C then allowed to stand for 5 minutes so that the wax hardened. Before pouring, cement mold and RTV rubber mold were coated with non-sticky liquid, so that the wax can be easily removed from the mold.

![Figure 6a. Paraffin and dammar gum.](image1)
![Figure 6b. Mixture.](image2)
![Figure 6c. Solid.](image3)

2.5. Measurement
Printing with molds made of cement and silicon rubber is carried out three times. The printout is measured in the plane of height, length, thickness, and width. The mold measurement area is as shown in Figure 7. After the measurement process, the percentage of dimensional distortion in each field is calculated.

![Figure 7. Measurement area.](image4)

A1 = the Outer Height
A2 = the Inner Height
B1 = the Outer Length
B2 = The Length of point 2 to 2
B3 = The Length of point 3 to 3
B4 = The Length of point 4 to 4
B5 = The Length of point 5 to 5
B6 = The Length of point 6 to 6
C1=C2=C3=C4 = The Difference of A1 and A2
D1 = width of Origami Pattern
D2 = Width of the edge to the middle diamond
D3 = Width of the edge to the outer angle
D4 = Width of the edge to the Inner angle

3. Results and discussion
The result of cement mold can be seen in Figure 8.a and the result of RTV Silicon Rubber mold can be seen in Figure 8.b. Both of them have succeeded in making the origami crash box. From Table 1, the differences in design dimensions of cement mold and RTV Silicon Rubber mold can be seen. It shows a significant difference between cement and RTV Silicon Rubber materials. In area A was obtained the percentage data of the added dimensions of 1.6 percent on Portland cement molds and 0.7 percent on silicon rubber molds, for area B added 2.6 percent percentage occurs in cement molds and 1.9 percent on silicon rubber molds. Significant differences are found in area C, the percentage of the added dimensions on cement molds is 43.9% and on silicon rubber rtv molds is 4.4%, while in the area D the percentage of added molds are made from cement and silicon rubber rtv are 10.2% and 3.25%, respectively, as shown on Figure 9.

![Figure 8. Results of wax molds.](image)

The biggest percentage of added dimension in the overall is area C, which is an uneven thickness, this is because the workmanship is done manually, then the surface could not be precision between one point and another point. In silicon rubber RTV, it takes the release of silicon rubber RTV from the holder every time we print the wax, when it is reassembled on the holder, RTV silicon rubber is no longer precise with the holder, and affects the 2nd and 3rd molds. The percentage difference between design and cement was 14.7% while the difference between design and RTV Silicon Rubber was 2.7%. This proves that RTV Silicon Rubber can form more precise patterns than cement. RTV Silicon Rubber structure that has good formability, can mold patterns precisely, the pattern of casting wax into silicon rubber mold has not changed the geometry of silicon rubber because the wax pouring temperature, which is 50°C, is still below the Maximum Service Temperature, which is 226.5°C. However, further research needs to be done if RTV silicon rubber mold is used in a large scale.
As for roughness, through observation and touching on the surface, cement-based mold is smoother than RTV Silicon-based mold because cement mold is processed twice, the first process is modeling and the second process is smoothing. This is different from RTV Silicon Rubber mold which only takes one process. If the pattern is smooth then the mold will also be smooth, and vice versa. In Figure 8.b the result of mold follows the 3D printing pattern. The execution of cement pattern in the second workmanship was done manually, so it affects the precision of the mold. The more thorough the manual work is, the precision level will also increase.

Table 1. Comparison of the dimensional percentage of dimensional distortion.

| Dimension | Cement Average (mm) | Cement Percentage (%) | Silicon Rubber Average (mm) | Silicon Rubber Percentage (%) |
|-----------|---------------------|------------------------|----------------------------|-----------------------------|
| A1        | 124.6               | 1.1                    | 125.2                      | 0.6                         |
| A2        | 117.4               | 2.1                    | 119.17                     | 0.7                         |
| B1        | 151.3               | 0.8                    | 146.00                     | 2.7                         |
| B2        | 114.0               | 5.2                    | 110.33                     | 1.8                         |
| B3        | 123.0               | 1.2                    | 119.67                     | 1.5                         |
| B4        | 116.0               | 0.5                    | 115.87                     | 0.4                         |
| B5        | 120.0               | 4.8                    | 116.33                     | 1.6                         |
| B6        | 111.8               | 3.1                    | 112.40                     | 3.7                         |
| C1        | 4.2                 | 38.9                   | 3.03                       | 1.1                         |
| C2        | 4.5                 | 50.0                   | 3.07                       | 2.2                         |
| C3        | 4.5                 | 48.9                   | 3.20                       | 6.7                         |
| C4        | 4.1                 | 37.8                   | 3.23                       | 7.8                         |
| D1        | 39.4                | 1.5                    | 41.00                      | 2.5                         |
| D2        | 24.0                | 29.9                   | 35.67                      | 4.1                         |
| D3        | 38.1                | 0.8                    | 38.80                      | 2.7                         |
| D4        | 31.4                | 8.4                    | 33.07                      | 3.5                         |
| Average   | 14.7                |                        | 2.7                        |                             |
4. Conclusion
   a. The percentage difference between design and cement was 14.7% while the difference between
design and RTV Silicon Rubber was 2.7%.
   b. RTV Silicon Rubber mold can be more precise than cement mold. RTV Silicon Rubber mold is
   able to form complex patterns. The surface roughness adjusts to the imitated pattern, if the pattern
   is smooth then the surface produced by RTV Silicon Rubber mold is smooth, and vice versa.
   c. Cement mold tends to be smoother
   than RTV Silicon Rubber mold because cement mold can be
   processed and smoothed again after the pattern is pressed.
   d. Printing results from 3D Printing are still rough. It affects the mold products, especially RTV
   Silicon Rubber mold. Therefore, further finishing is required, both evaporating and coating of the
   product.

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