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# Manufacture of Origami Pattern Crash Box Using Traditional Investment Casting Method

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**Abstract.** The origami pattern crash box has the advantage of producing a predictable mode collapse because it has a pre folded pattern. Investment casting method can be used in the manufacture process of an origami pattern crash box because it can make a complicated product and does not require a lot of machined processes. This study used traditional investment casting with several stages, the first stage was making the wax mold, the second stage was coating the wax mold with calcium bentonite and mixture of soil, husk ash and water. The third stage was heating, the fourth stage was pouring and the fifth stage was finishing. In this research, two metal casting products with origami pattern crash box model were made with the thicknesses of 2 mm and 3 mm. It can be concluded that the result of the 2 mm origami pattern crash box casting cannot be shaped like the design because the liquid metal is unable to enter the mold cavity since it is too narrow. The result of the 3 mm origami pattern crash box casting can be shaped like the design. The casting results have a lot of defects, one of the causes is that the slag has not been thoroughly cleaned before casting. The surface is not smooth evenly since the first coating material is too thin, resulting in direct contact of the liquid metal to the second material layer, which is rough. Future research requires a smooth refractory material to coat the wax mold and further research using investment casting method with high precision that has been developed in the industry.

## 1. Introduction

Tubular crash boxes with various patterns are located between the bumper and the chassis of a car. They serve as a kinetic energy damper when the car has an accident. Research on crash box develops by modifying patterns and materials of crash box in order to obtain high kinetic energy absorption. Research on crash box pattern develops to folding mechanism, that is crash box would have symmetrical buckling when collision accompanied by buckling happens. One of the research regarding this matter is the crash box developed by Ma J and You Z [1] who developed the origami pattern crash box which has the advantage of pre folded pattern on the crash box. On the comparison of low speed impact test with conventional tube crash box, the origami pattern crash box increased the energy absorption to 92.1%. The development of Origami Pattern Crash Box on high speed impact test was conducted by Kusyairi, et al. [2], while testing of origami pattern crash box at angle directions was conducted by Bintarto, et al.



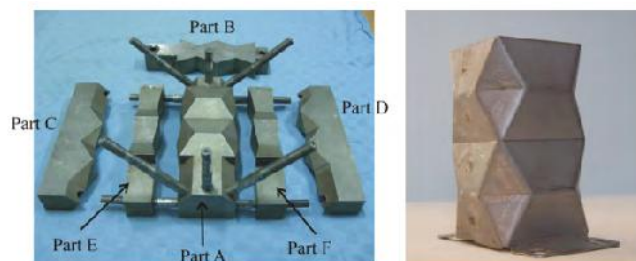
[3] and Zhou et al. [4]. Research on origami pattern crash box continues by applying it on MPV cars [5] and equalizing the size of the crash box and the chassis. It is concluded that the origami pattern crash box produces a predictable mode collapse because it has a pre folded pattern that serves to pass on the kinetic energy to all parts of crash box structure.

Research on the process of origami pattern crash box manufacture was conducted by Ma, Jiayao [6]. The method used to manufacture the origami pattern crash box was stamping method, as shown in figure 1, by making the mold with groove pattern curves. The mold was used to press and combine plates using Gas Tungsten Arc Welding (GTAW). The result of welding is harder if it is done at a specific temperature. Therefore, the annealing process was done at 600oC for 30 minutes and the plates were cooled down in the furnace.



**Figure 1.** Mold Stamping (a) Stamp (b) Product Stamping

Ma, Jiayao also developed a different stamping method by making a stamping consisting of six parts that could cover half of the origami pattern crash box as shown in Figure 2. The plates were placed in the center then pressed on each corner. The tip of the plates was combined by welding, the same way as the previous experiment. This method is effective in manufacturing origami pattern crash box.

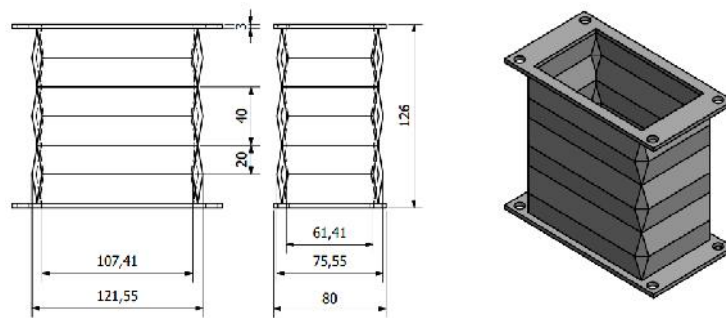


**Figure 2.** Mold Pressing

Another method that can be used for the fabrication process of origami pattern crash box is the lost wax method that is commonly known as investment casting. This method can make a complex pattern in one processing. Research on investment casting has been done a lot by researchers, research to obtain the composition of primary slurry by Singh, et al. [7], research on the influence of ceramic shell composition differences [8,9,10], research on the effect of substitution material addition on ceramic shell [11]. In this research, origami pattern crash box was made using traditional investment casting method. The research location was at home industry in Mojoagung, Jombang.

## 2. Method

The design of Origami Pattern Crash Box is adapted from previous research [5], where the origami pattern crash box has a rectangular cross section which size is adjusted to MPV cars as in figure 3. Thickness of objects processed in metal casting are 2 mm and 3 mm respectively. Each processing is shown in Table 1. The difference of processing is the 3D printing modeling to be used in the processing, wax mold is expected to fit the size designed in CAD and have a higher precision than the wax mold that is not made with 3D printing reference.



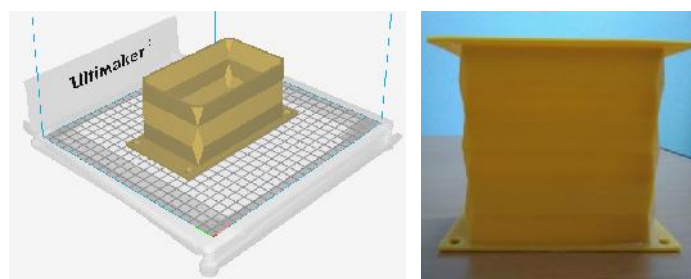
**Figure 3.** Design of Origami Pattern Crash Box

**Table 1** Differences in Processing

Processing	Thickness of Origami Pattern Crash Box	
	2 mm	3 mm
CAD Design	Yes	Yes
3D Printing Modeling	No	Yes
Wax Mold Manufacturing	Manual Measurement	3D Printing Result Adjustment
Cement Layering	Yes	Yes
Clay Layering	Yes	Yes

### 3D Printing Process

The 3D printing process requires the file to be converted from .ipt to .stp as shown in Figure 4.a with cura software. After being converted, the printing process starts using PLA filament material, which is a thermoplastic material and commonly used for 3D printing material. This material is able to be melted by heating, the material temperature is at 120°C to 200°C and the 3D printer base is at 60°C for printing. PLA material has an advantage of insensitivity to temperature changes that occur during the printing process and it is easy to print. In the process of making 3D printing, the printing process is done in two stages, as shown in Figure 4, to avoid failure due to a sudden disconnected power supply, because printing an intact origami pattern crash box takes 51 hours, 24 minutes. Results obtained from 3D Printing is shown in Figure 4.b.



**Figure 4.** Modeling in CURA Software

### Wax Mold Making

The making of wax mold of 2 mm origami pattern crash box was done manually by combining wax sheets measured with ruler according to the information of size obtained from Figure 5, while the 3 mm origami pattern crash box was done by equalizing the size of wax mold with the 3D printing result. The process of making wax mold has to be done quickly before doing the next step. It is caused by the nature of wax that will change form if it is exposed to room temperature for too long and it makes the results of the casting asymmetrical and the cast will not be precise. The result of wax mold and gate manufacture is shown in Figure 5.



**Figure 5.** Wax Mold

### Layering

There are two stages in this process, the first stage is layering the wax mold of origami pattern crash box with Calcium bentonite, which has physical characteristics of white gray flour like texture and turning slippery when it is mixed with water. It aims to obtain smoothness on the cast. After the first layering stage, wait for the calcium bentonite to dry at room temperature. In the second stage, the following process is carried out by layering the mixture, the mixture composed of husk ash mixed with clay and water, then the mixture is applied to the origami pattern crash box as shown in Figure 6.



**Figure 6.** Layering Process

### Wax Mold Heating

The wax heating process is divided into two stages, the first stage, as shown in Figure 7.a, is the heating done under the warm sunlight to avoid the occurrence of cracks on the workpiece. The purpose in this first stage is to evaporate the residual water contained in the workpiece. In the second stage, as shown in Figure 7.b, the dry workpiece is heated in the furnace, it is placed upside down. In this heating process, the wax flows out of the gate that has been designed, this gate serves for entry and exit of aluminum during casting, and the manufacture of origami pattern crash box is completed.



a. Heating Stage 1



b. Heating Stage 2

**Figure 7. Mold**

### **Metal Pouring**

The process of pouring aluminum from the aluminum combustion furnace into the mold. Before the casting process, make sure that the slag of aluminum combustion is cleaned first, as this will cause defects in the cavity of the casting due to the flow of liquid metal is clogged. The process of pouring the metal into the mold should not be interrupted and make sure that the liquid metal is fully filling the mold. It can be seen when the aluminum flows out of the other gate. In figure 8, the workpiece is ensured in an upright position, it helps the process of metal liquid flow when it fills the mold.

**Figure 8. Metal Pouring**

### **Removing and Finishing**

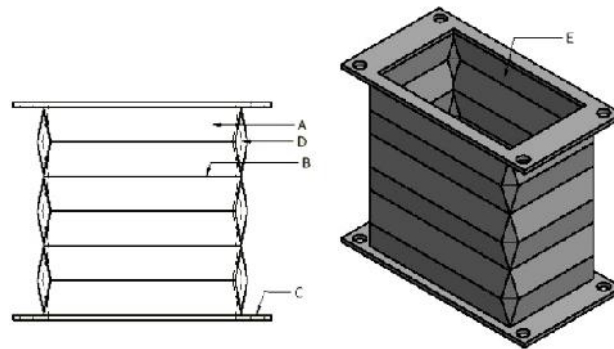
After ensuring the molten aluminum freezes, the next process is to remove the mold from the aluminum as shown in Figure 9, i.e. the process of removing the soil mold from the workpiece. The next step is to cut the gate (metal fluid duct), check the cast and identify the defects of the cast. If any defect is identified and it cannot be fixed, it has to be re-melted. However, if the workpiece can be fixed in the finishing process, machined process will be done to get a better product.

**Figure 9. Casting Product**



### ***Roughness Measurement***

The next stage after finishing the machining process is the roughness measurement of Traditional Investment casting products. Generally, it will measure the outer surface area represented by area A as many as 3 points, outside measurements of indentation area is represented by area B as many as 3 points, measurement of the lower outer area is represented by area C as many as 3 points, roughness measurement of the angular part is represented by area D as many as 4 points, and the roughness measurement of the inner part is represented by area E as many as 4 points as shown in figure 10.



**Figure 10.** Origami Pattern Crash Box

Where:

A is the outer surface area

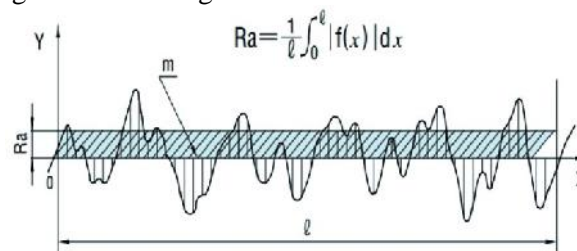
B is the outer surface of indentation line

C is the outer surface of bottom part

D is the outer surface of corner

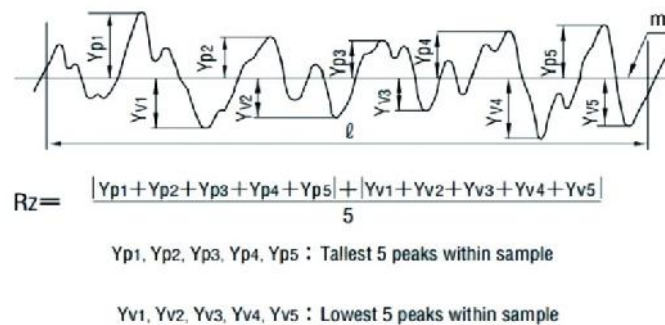
E is the inner surface

Measurements were made along 1.2 mm per point, to obtain values from the arithmetic mean values from measurements of surface roughness for a certain length ( $R_a$ ) and measurements based on the average values of the five highest peaks and the lowest five valleys ( $R_z$ ). The  $R_a$  (Roughness Average) is usually called as the roughness of the arithmetic average, which shows the average absolute value along the length of sampling as shown in figure 11.



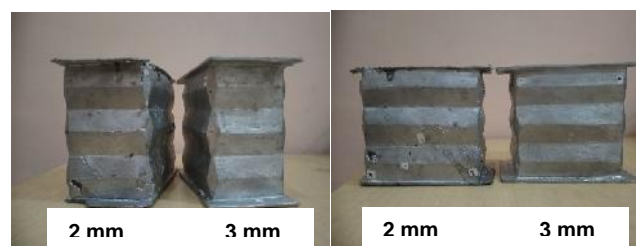
**Figure 11.**  $R_a$  Calculation (Roughness Average)

$R_z$  is the calculation of the sum of the absolute average heights of the five highest profile peaks and five the highest profile peak. Measurement method is done by taking a number of samples, for example 10 areas, namely 5 peak and 5 valley areas. Then make a horizontal straight line below the surface profile. Make perpendicular lines from each end of the peak and valley to the horizontal line, as shown in figure 12.

**Figure 12.** Rz Calculation

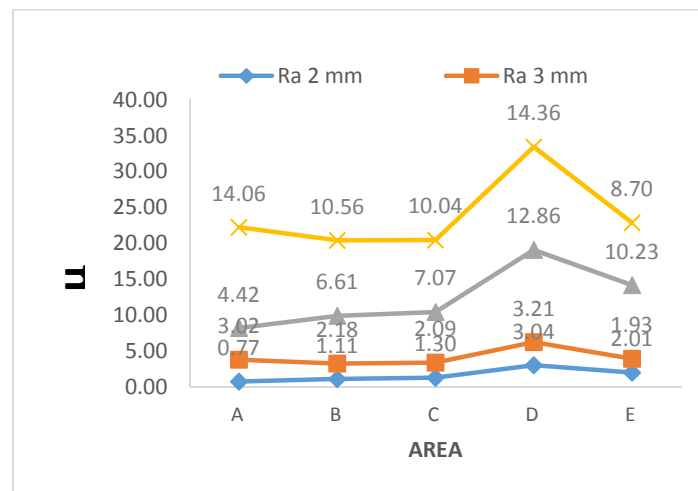
### 3. Research Results

The results of casting with the Traditional Investment Casting method on the Origami pattern is shown in figure 13. The pattern of the casting with a thickness of 2 mm is not able to form completely, a lot of aluminum liquid is not able to enter the corner, while the casting with a thickness of 3 mm aluminum is able to fill a few points perfectly but still has a subtle shape.

**Figure 13.** Results of Traditional Investment Casting

The roughness results of each casting can be seen in Figure 14. In general, it shows that the pattern of 3 mm has a roughness of Ra and Rz which is higher than the pattern of 2 mm, both in the long, indentation, bottom, corner and interior. The average roughness of all areas in the 2 mm and 3 mm patterns is 1.64  $\mu\text{m}$  and 2.49  $\mu\text{m}$ , respectively. The high points of irregularities (Rz) ten points in the 2 mm the 3 mm patterns are 8.24  $\mu\text{m}$  and 11.54  $\mu\text{m}$ , respectively. The highest roughness is found in area D which represents the corner area, and the second area is area E, which represents the inside, this is because the wax changes the shape in the corner and clay filling to suppress imperfect wax and Portland cement coating which is not comprehensive in every corner, this is also evident in the inner pattern which has a high roughness value, which is indicated by the first phase of coating which is not comprehensive and also the second stage coating which does not reach the area. But in area A that represents the outer length, area B which represents the outer indentation and area C that represents the bottom appears to have a stable Ra value.







**Figure 14.** Result of Roughness Measurement Ra and Rz









As seen in Table 2, there are some significant differences in the results of metal casting in the form of defects on the casts. In the picture, it can be seen that the 2 mm crash box cast has a lot of defects and uneven surface, the aluminum does not reach the top and bottom, also the corner of the cast. The 3 mm crash box cast is shaped, the top and bottom are also shaped, but the thickness of each side is uneven, there are various thicknesses, 3 mm to 4 mm, when measured. It means that the result is precise with the CAD design. The level of smoothness of both crash box casts is also not much different because Calcium bentonite provides a low level of refinement for automotive products.

The defect that occurs on the cast is crack that occurs due to the non-uniformity of the mold thickness planning process. It happens due to the change in the wax mold that affects the flow of the liquid aluminum and resulted in misrun. On the 2 mm crash box, there is a misrun because the workpiece is too thin and the pouring is not fast enough. Roughness of the surface occurs because the layer of calcium bentonite is too thin, this layer is unable to hold the mixture of soil, husk ash and water when during the layering and heating process. Therefore, a refractory material is required. Not only heat resistance, this material is also smooth, it will improve the smoothness of the cast.

There are some mismatches between the inside of the 3 mm crash box and the design. There are some holes on its corner because the Aluminum has been oxidized and the slag was not thoroughly cleaned which leads to the halting of the liquid aluminum flow to the corner. This also happens to the 2 mm crash box, the liquid aluminum does not fill the cavity fully because the mold is thin and the slag is not thoroughly cleaned.

**Table 2.** Metal Casting Result

View	Thickness of Origami Pattern Crash Box	
	2 mm	3 mm
Front view		

View	Thickness of Origami Pattern Crash Box	
	2 mm	3 mm
Back view		
Right side view		
Left side view		
Top view		

#### 4. Conclusion

From several research results above, it can be concluded that:

1. Product of the 2 mm diameter Origami Pattern Crash box casting cannot be shaped completely because the liquid aluminum material has been oxidized and there is slag on the mold, so the liquid aluminum is unable to pass through the 2 mm cavity.
2. Product of the 3 mm diameter Origami Pattern Crash box casting can be shaped like the CAD design but the thickness is uneven at several points.
3. Smooth refractory material is required to layer the wax mold.
4. Further research using investment casting method with high precision that has been developed in the industry is also required.

#### Acknowledgement

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