Journal of Advanced Research in Mechanical Engineering and Technology
Volume 8, Issue 3&4- 2021, Pg. No. 13-29
Peer Reviewed Journal

Research Article

Sand Mold Design for Casting Recycled Aluminum Pots: An Improved Process from Artisanal Methods

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E-mail Id:
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How to cite this article:
Samon JB. Sand Mold Design for Casting Recycled Aluminum Pots: An Improved Process from Artisanal Methods. *J Adv Res Mech Engi Tech* 2021; 8(3&4):13-29.

Date of Submission: 2021-12-09
Date of Acceptance: 2022-01-20

A B S T R A C T

The artisanal molding of recycled aluminum pots with green sand is a molding process based on the craftsman's personal experience. Our study consists in proposing to craftsmen an improved process of local molding aluminum pots. This activity often based on the craftsman's subjective sizing experience, sometimes, causes casting failures without a valid explanation or justification. To achieve a more improved process of artisanal casting of aluminum pots, we have illustrated two complete casting processes using two shapes of pots widely used at the local level: To control the casting variables such as the shape of the molds, the controlled filling and cooling rates to minimize molding defects, we used basic engineering principles based on the sizing of the mold, in particular, the pouring system (filling pocket, sprue section, channel section, gating system section) and feeding system (Riser). To do this, we presented the artisanal process used by craftsmen. The optimized sizing allows the production of rigid pots and good qualities of mechanical properties. This new approach also makes it possible to reduce recurring defects and hardship of workers to increase the profit of tiny businesses.

Keywords: Casting, Traditional Casting, Mold Design, Sizing, Recycled Aluminum, Green Sand

Introduction

Without kitchen utensils, humans cannot cook food. Pots are used in all homes and restaurants to prepare different meals. Aluminum pots are the most widely used in Africa because of their rapid heating and cooling capacity. They are light, reasonably resistant, affordable, and recyclable.

The foundry is one of the main bases for industrial development, particularly the sand foundry, that is to say, sand casting. It is a versatile method and the most used in foundry. Casting is a set of processes for making raw metal parts by pouring molten metal into sand or metal mold. The mold is the set of appropriate elements, delimiting the imprint and receiving the liquid metal, which will give the part.[1] In Central Africa, this aluminum foundry technology is used by craftsmen to cast aluminum pots with green sand. To make their kettles successful, workers use many subjective skills to control a large number of process variables though they often end up with castings that are faulty or scrapped due to possible incorrect factors. This lack of control in-depth techniques on molding variables, particularly the design of the mold the control of the aluminum filling rate in the cavity and the cooling rate control, and the formulation of the sand mixture despite their commendable practical competence.

Therefore, successful sand casting requires meticulous control of a large number of metallurgical and mold design variables. Correct mold design with the flow and cooling rate controls of the molten metal in the mold cavities is the basic for successful casting and reducing the labor involved. Mold design requires establishing requisite specifications of the pouring basin, sprue, sprue well, runner, gating system, product cavity, and cooling means to achieve satisfactory products of various types and sizes. Improper mold design can cause oxidation of molten metal, misruns, mold erosion, and failure with attendant costs. In foundries, more significant engineering skills and creativity are used to control many process variables to eliminate or minimize defects in castings and achieve higher production rates with less labor compared to artisanal casting practices[2] from.[3,4]

The mold is made up of two halves the copes (upper half) and the drag (bottom half), which meet along a parting line. Both mold halves are contained inside a box called a flask divided along the parting line. The two halves of the mold are placed together by using pins called dowel pins. The mold cavity is formed by packing sand around the pattern in each half of the flask. When sand is packed and the pattern removed, a cavity that forms the external shape of the casting remains. Cores may form some internal surfaces of the casting. Sand casting involves the use of green or dry sand molds. Cores are additional pieces that form the internal holes and passages of the casting. Cores[2,5] are typically made of sand to be shaken out of the casting Figure 1, shows a typical mold arrangement for sand casting.

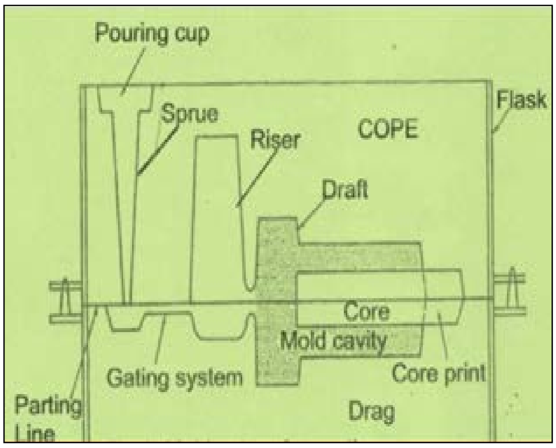


Figure 1.Mold set-up for casting[2]

The sand used for molding is transformed into a malleable paste made up of excellent grains of moistened silica. It meets the following requirements: having a smooth surface as far as possible, reproducing faithfully the model part, resisting the high casting temperature of the metal (have a softening temperature higher than the melting temperature of the alloy), Resisting erosion of liquid metal, and do not oppose the passage of gases produced at the time of casting. The composition of the green sand is generally [6]: 70 to 80% silica (support), 5 to 15% clay (binder), 7 to 10% water, 3 to 5% impurities (iron oxide, organic matter).

The design of the casting cluster consists in modifying the geometry of the part to adapt it to the process, then adding the appendages necessary for filling and solidifying the impression, each step must prevent the generation of defects during casting.

A molding defect is an undesirable irregularity in a part obtained by molding and characteristic of the production process and the cast metal. Some faults can be repaired, but they can also lead to a scrap of the part. We can distinguish five categories of defects, based on their mechanisms of formation, namely [6]: the defects formed during shrinkage and which are linked to solidification (shrinkage, cracks, tapures), the gas faults (blowholes), the defects related to the material with which the mold is made (penetrations), the defects formed during mold filling: filling defects and the production defects (defects in the parting line). The artisanal casting process of aluminum pots follows a significantly complex chain of operations that requires prior skill and mastery. The manufacture of a cooking pot requires the mastery of a succession of technical gestures, which must be carried out with great skill and precision given the small thickness of the object's walls. Depending on the technical resources available, the metals and alloys used, the number of objects to be produced, and the desired degree of finish, there are several molding methods.[7,8] Our study consists in proposing an improved process to insist on using fundamental engineering principles to complete the artisanal process to ameliorate the quality and productivity by minimizing the drudgery and the rejects to maximize the company profits. Thus, this work is structured in four sections, which begin with a brief review of literature on sand casting, followed by the casting methodology, the design casting method, and end with the presentation of the results and discussion of findings.

Casting Methodology

Materials used

Artisans produce several shapes of pots using green sand in a mold whose pouring boxes are made of wood, made from aluminum melted in a traditional oven made from refractory clay. After the surveys on artisanal molding, the following materials used caught our attention. The most widely produced pots are cylindrical pots with particular shape (pot does everything) (Figure 2).

Figure 2.Different shapes of pots: (a) Cylindrical pot, (b) Pot does everything

The footprint is defined by sand, and the crate is made of wood. The sand used is "green sand." Greensand is made up of clay, silica, a black mineral, and water. It hardens when strongly compressed and becomes refractory. For artisanal casting, the aluminum used is the result of the collection of spare parts from car garages and other recyclable aluminum waste collected throughout the city. Recovered aluminum is often associated with parts of different nature (steel screws, copper windings, plastic elements, grease or water. It is therefore essential to sort and clean the collected waste as illustrated in Table 1.

Table 1.Sorting of Aluminum

Origin	Name	Status of use
Automotive industry: crankcases, engine blocks	"Normal" alloy	Used as is or weakly mixed with another alloy
Automotive industry: pistons, cylinders, crankcases or cylinder heads very rich in magnesium	"Hard" alloy	Mixed with 70 to 90 % soft alloy
Building profiles (door frames, etc.), beverage cans, printing plates or scrap from the stamping of aluminum plates	"Soft" alloy	Mixed with 10% to 50% hard alloy

When sorting, set up a device to recover any oil residues that may be present in certain parts.

The melting of the charge and the pouring of the liquid metal are important steps in the production of castings. This is where the quality of the alloys and the quality of the finished part is determined. Although aluminum and its alloys have low melting temperatures compared to other materials such as steel or copper alloys that are also cast by the craftsman, their main drawback in this application is their great affinity for oxygen in the solid and liquid state. This is the reason why aluminum and its alloys spontaneously cover themselves with a layer of alumina in the solid state (from room temperature) as well as in the liquid state and absorb other gases such as hydrogen in the liquid state which form small bubbles in the metal called pores at the time of solidification.

The amount of slag formed is a function of the alloy's production temperature and the length of time the liquid bath remains at that temperature. Under these conditions, to lose as little metal as possible, the melting must be as fast as possible and at the lowest possible temperature, compatible with the casting conditions. To limit the contact of the liquid metal bath with the air, it would also be logical to use a crucible with a small opening. The crucible should therefore be filled with aluminum and its alloys, the crucible should be covered effectively during the melting process and the aluminum scrap should be compacted before being introduced into the crucible, the aluminum should be heated to a temperature above its melting point and sodium chloride should be added to the molten metal in order to eliminate the slag.

Casting pans are thin and therefore the control of the casting temperature is also a factor to be taken into account in the quality chain of the pans. The viscosity of the liquid alloy is a function of the temperature. The more fluid the alloy is, the better its flowability, hence the better ability to fill the mold and to follow its contours.

The furnace used to smelt the aluminum is constructed of fireclay and fueled by coal as depicted in Figure 3.

Figure 3.Local Furnace

If there is no thermometer, the color of the bath and the melting temperature can be identified: barely visible (630°C), visible (675°C), dull red (775°C), dark red (850°C) and bright red (990°C).

The sand used must be treated. Fine sand (0.5 - 1 mm) and very fine sand (0.1 - 0.5 mm) should be mixed with clay and water. Unused sand should be sifted separately and mixed: 30-40% fine sand, 40-55% very fine sand, 15-20% clay and 4-10% water.

Casting Aluminum Pot Methodology

The methodology for molding pots follows logic of steps in chronological order, the non-observance of which inevitably leads to failure of molding (defective pot). It is divided into 03 main stages, as indicated in Figure 4.

Casting Cluster construction method

Sizing the complete mold consists of finally obtaining the sprue, which defines the total footprint of the pattern part. This part consists of starting from the dimensions of the initial part to obtain the dimensions of the pattern and taking into account the modifications, which are the sizing of the pouring system and feeding systems as indicated in Figure 5 below.

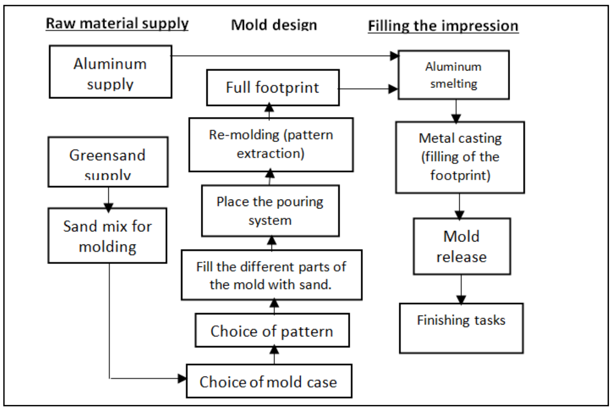


Figure 4. Casting Methodology for Aluminum Pots

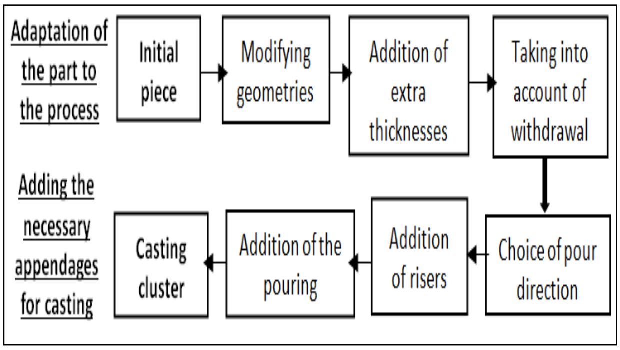


Figure 5.Casting Methodology for Aluminum Pots

Design Method

This method allows us to apply the casting cluster construction method by following the foundry logic for the two types of pots proposed.

Proposition I: A pot of Cylindrical Shape

For this cylindrical pot, Figure 6, illustrates the nominal dimensions of the original part, and table 2 presents the characteristics.

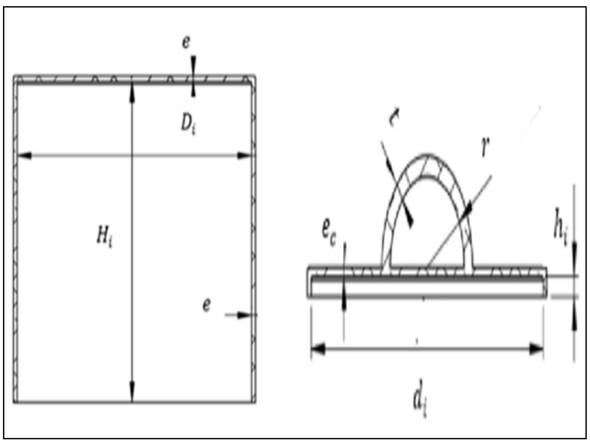


Figure 6.Nominal dimensions of the cylindrical kettle

Table 2. Nominal Dimensions of the Pot

Nominal dimensions of the pot body		
Dimensions	**Designations**	**Relationship**
Thickness	*e*	Given value
Internal diameter	D_i	Given value
Outside diameter	D_e	$D_e=D_i+2e$
Interior depth	D_e	Given value
Volume	V_m	$V_m = \frac{\pi}{4}[(D_e^2 - D_i^2)H_i + e.D_e^2]$
Nominal dimensions of the cover		
Thickness	e_c	Given value
Internal diameter	d_i	Given value
Outside diameter	d_e	$d_e=d_i+2e_c$
Interior depth	h_i	Given value
Lid volume	V_c	$V_c = \frac{\pi}{4}[(d_e^2 - d_i^2)h_i + e_c.d_e^2]$
Nominal dimensions of handling lugs		
Ray	*r*	Given value
Thickness	*t*	Given value
Volume	V_{em}	$V_{em} = \pi\frac{t^2}{2}[2r + t]$

Design of the pattern (adaptation of the part to the process)

To obtain the desired part with its exact dimensions, the design of the pattern must take into account the metal shrinkage allowance, machining allowance, and undercuts.

Shrinkage and Machining Allowance: The allowances must be added to respect the dimensional tolerances of the pot. The pot is scaled to take into account the concrete shrinkage of the metal during cooling. So the dimensions of the model are greater than those of the part to be molded. Suppose a shrinkage allowance of 1.5% = 0.015mm for aluminum and its alloys (see appendix 2) and the machining allowance (MRA) is chosen according to the largest dimension of the part (see appendix 5). The calculation of the dimensions of the pattern must take into account the formula for excess thickness and shrinkage. The drafts depend on the sharp angles and the choice of molding direction (parting line).

Patterndimension=Partdimension±excessthickness

For this cylindrical pot, Figure 7, illustrates the nominal dimensions of the model and in Table 3, their characteristics.

Table 4, summarizes the volume and mass of the alloy required for the molding of the pot.

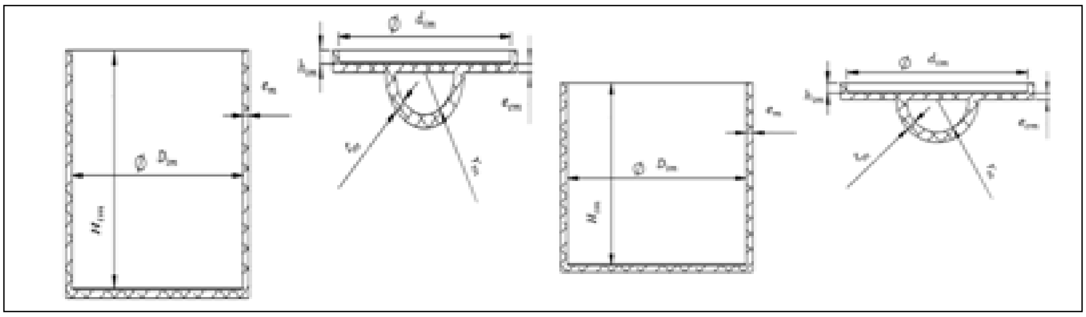


Figure 7.Nominal dimensions of the wooden pot pattern

Table 3.Nominal dimensions of the wooden pot pattern

Nominal dimensions of the kettle body pattern		
Dimensions	**Designations**	**Relationship**
Thickness	e_m	$e_m=(e+2MRA)(1+S_r)$
Internal diameter	D_{im}	$e_m=(e+2MRA)(1+S_r)$
Outside diameter	D_{em}	$D_{em}=D_{im}+2e_m$
Interior depth	H_{im}	$H_{im}=(H_i+2MRA)(1+S_r)$
Volume	$V_{pattern}$	$V_{pattern}=\frac{\pi}{4}[(D_{em}^2-D_{im}^2)H_{im}+e_m.D_{em}^2]$
Nominal dimensions of the lid pattern		
Thickness	e_{cm}	$e_{cm}=(e_c+2MRA)(1+S_r)$
Internal diameter	d_{im}	$d_{im}=d_i-2MRA$
Outside diameter	d_{em}	$d_{em}=d_{im}+2e_{cm}$
Interior depth	h_{im}	$h_{im}=(h_i+2MRA)(1+S_r)$
Lid volume	$V_{(cm\_pattern)}$	$V_{cpattern}=\frac{\pi}{4}[(d_{em}^2-d_{im}^2)h_{im}+e_{cm}.d_{em}^2]$
Nominal dimensions of the handling lugs pattern		
Radius	r_m	$r_m=r-MRA$
Thickness	t_m	$t_m=(t+2MRA)(1+S_r)$
Volume	$V_{(em\_pattern)}$	$V_{cpattern}=\frac{\pi}{4}[(d_{em}^2-d_{im}^2)h_{im}+e_{cm}.d_{em}^2]$

Table 4.Raw Materials Needed for Molding

Characteristics	Computation formulas of Raw material needed for molding
Footprint volume	$V_{(T\_pattern)}=V_{(m\_pattern)}+V_{(c\_pattern)}+V_{(em\_pattern)}$
Aluminum mass	$M_{a\_shrinkage}=\rho\_a.V_{T\_pattern}$
Cost of aluminum	$M_{a\_shrinkage}=\rho_a.price$
Mass of sand	$M_{sand}=(V_{frame}-V_{footprint})\rho_{sand}$
Water for sand dosing	$V_{water}=M_{sand}\times\%water$

Adding Appendages to The Casting

Solidification orientation method: Solidification is at the heart of metallurgy and the foundry principle. Good solidification leads to healthy parts with a respected dimension. Failure to follow the orientation leads to a sinkhole and crack.

Pouring system sizing (Riser)[10]: The risers are liquid metal reserves intended to feed the part during its cooling and compensate for the volume shrinkage that the metal undergoes. It is added during the design of the foundry cluster cooling after the part to displace shrinkage defects. Chvorinov formula governed its sizing.[9]

- The cooling module

$$M_r = \frac{V_{pc}}{A_{pc}} = \frac{volumeofonepartofthepart}{coolingsurfaceofthatpartofthepart}$$

- Solidification time

According to Chvorinov's law, the solidification time is:

$$T_s = \beta\left(\frac{V_{pc}}{A_{pc}}\right)^n = (M_r)^n \begin{cases} T_s: solidificationtimeinseconds \\ M_r: coolingmodule \\ nisbetween\ 1.5 \text{ and } 2 \\ \beta isaconstantdependingonthealloyandthemoldtemperature \end{cases}$$

- Verification conditions

Riser volume : $V_{riser} \geq r.V_{part}.k$

With r, the volumetric shrinkage and k a coefficient depending on the type of riser.

Riser module: $M_{riser} \geq 1.2M_r$

Sizing of the Pouring Aystem

The role of the pouring system is to direct the metal from the ladle to the part. It is necessary to establish a pouring while keeping the same pressure in the gating system (short conduits, generally of reduced section and flat shape connecting the channels to the footprint of the part) as the temperature.

Bernoulli's Law and Choice of Staggering

Bernoulli's law makes it possible to determine the filling and outlet speeds of each section, and the staggering makes it possible to determine the different sections of the filling system: Sprue section (S_d), Channel section (S_c); gating system section (S_a). An abacus gives the scale according to the materials cast (See appendix 4). It allows to determine the channel and attack sections according to the sprue section. The presentation of the staggering is given according to the casting sprue section as follows:

$$\frac{S_d}{S_d} \rightarrow selectedvalueoftheappendix\ 4\ chart;$$

$$\frac{S_c}{S_d} \rightarrow selectedvalueoftheappendix\ 4\ chart;$$

$$\frac{S_a}{S_d} \rightarrow selectedthevalueoftheappendix\ 4\ chart.$$

Proposition 2: Pot "does everything."

The nominal dimensions (Figure 8) are given by drawing the pot (see appendix 7).

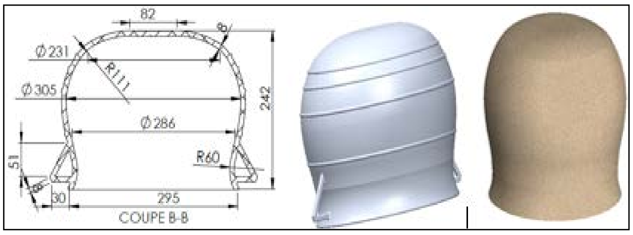


Figure 8.Nominal dimensions of the "does everything" pot with their core

The pattern is designed using the same principles as above and taking into account extra thicknesses. On average, the shrinkage is 1.5% = 0.015mm for aluminum and its alloys. Thus,

Pattern dimension=part dimension±excessthickness (setback+machining)

The system sizing methodology is the same as that of the cylindrical kettle. The molding range is all the different operations carried out according to specifications.

Description of the Process of Obtaining the Core

In the case of our study it is good to note that we will refer only to sand molding and a sand mold can be used only once. The mold consists of 03 parts: a lower part and two upper parts. In the case of a cast pot, the use of a durable core is not possible, because each removal from the mold requires the destruction of the core to bring out the cast pot. This is due to the complex and non-uniform geometric shape of the pot: the geometric shape is not constant throughout the height of the pot. As the core is destroyed at each demolding, it is necessary to design it in a fast and less expensive way: non-permanent core built with green sand.

It should be remembered that in the case of this type of pot casting, the model (pot) is divided into two equal parts by a plane of symmetry. It should be remembered that in the case of this type of pot casting, the model (pot) is divided into two equal parts by a plane of symmetry as shown in Figure 9.

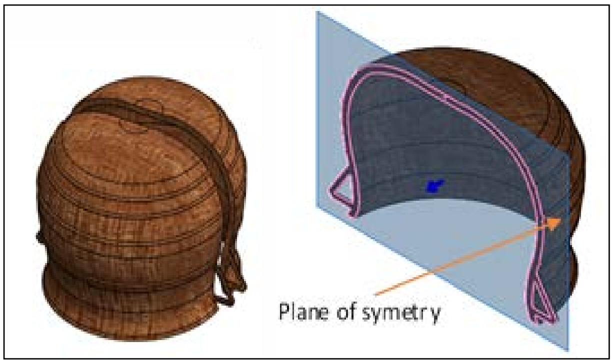


Figure 9.Pattern Pot

To obtain the core, the two parts of the model are assembled by a joint to form a complete pot. The principle is to assemble the two parts of the model pot, to fill the inside of the model pot with green sand, to pack the sand at the time and after the filling, to place the pot by its opening on the lower part of the mold (third part of the mold), to disassemble the model by removing the joint ensuring the maintenance in position of the two parts of the mold and finally to carefully remove the various parts of the model (Figure 10).

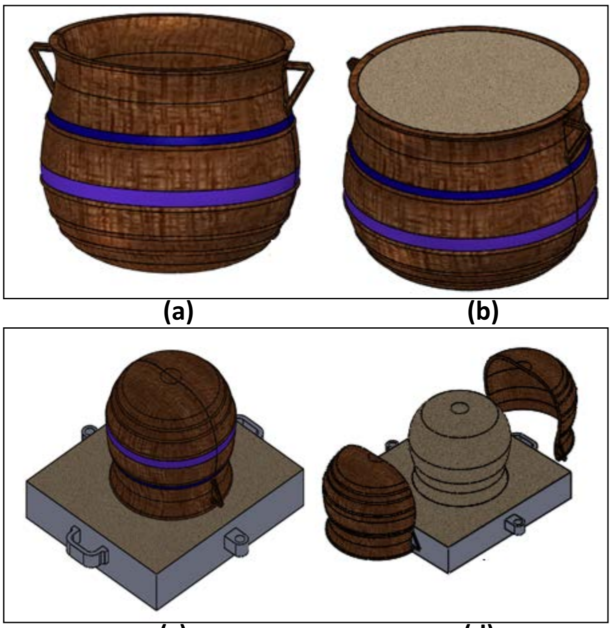


Figure 10.Assembling the model (a), Filling the inside of the pot with green sand(b), Placing the filled model on the bottom of the mold(c), Disassembling the model to obtain the core(d)

Results and Discussion

Handcrafted Molding Process

The artisanal process begins with the supply of aluminum and green sand. In this study, the aluminum used for the production of aluminum pots results from the collection of spare parts from motorcycles, cars, and other recyclable aluminum waste from household and automobile users. After collection, the mold design consists in defining the complete mold print of the model in the molding sand. The mold is made using a wet sand-clay mixture (green) with the dual property of hardening when strongly compressed and refractory. This allows it to resist without deforming in contact with molten metal. Figure 11, describes the artisanal process commonly used in the pot-making workshop. After supplying the raw material, the next step is the preparation of the mold, and at the end, the melting of the aluminum and the filling of the footprint.

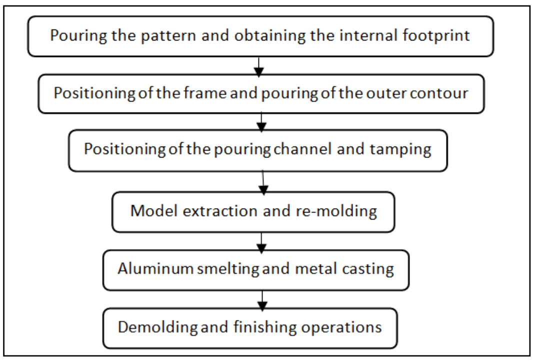


Figure 11.Handcrafted molding process

We note that the artisanal molding process adopted by craftsmen follows a quasi-formal chronological order at different stages of molding provided for by the molding methodology. Nevertheless, several states do not respect the molding rules according to engineering principles on the foundry, such as the sizing of the riser and the pouring system. Some negligible parameters emerge during the artisanal molding process, as summarized in Table 5.

Table 5.Parameters neglected during artisanal molding

S. No.	Parameters not respected	Impacts on the process	Impacts on the final part
1	Non-dimensioned pouring pocket	No control of the mold pouring speed	Lacks or defects in welds
2	Direct top pouring	erosion or pull-out of mussel sand	Penetrations
3	Lack of vents	air and gas entrapment	Blows
4	Molding case not chosen according to the standard	inability to overcome the static metal thrust	Modification of the shape of the part to be obtained

According to the table above, it appears that suitable sizing is necessary to reduce or even eliminate these risks and molding defects.

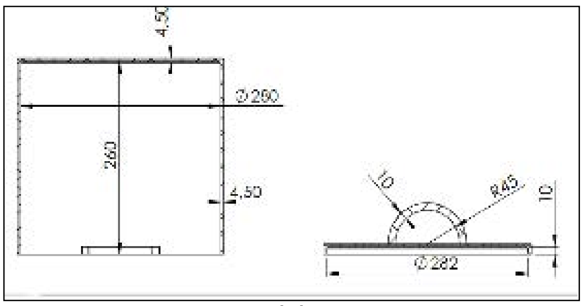
Method Proposed using Optimized Sizing

Proposal 1: Molding of the cylindrical pot with its cover

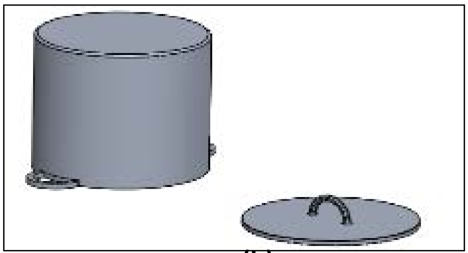
Calculation of The Nominal Dimensions of the Pot and its lid

For our study, we will illustrate our dimensioning by a cylindrical pot having the following nominal characteristics (Figure 12):

Thickness e = 4.5mm
Internal diameter D_i = 280mm
Interior depth H_i = 260mm
External diameter $D_e = D_i + 2e$ = 289mm



(a)



(b)

Figure 12.Nominal dimensions of the Pot and its Lid and their isometric views

Pot Body Volume

$$V_m = \frac{\pi}{4}[(D_e^2 - D_i^2)H_i + e.D_e^2] = V_m = \frac{\pi}{4}[(289^2 - 280^2)260 + 4.5(289^2] = 1340913mm^3$$

Lid Volume

$$e_c = 4.5mmd_i = 282mmh_i = 10mmD_e$$

$$V_c = \frac{\pi}{4}[(d_e^2 - d_i^2)h_i + e_c.d_e^2] = V_c$$

$$= \frac{\pi}{4}[(291^2 - 282^2)10 + 4.5(291)^2] \quad V_c = 339790.34mm^3$$

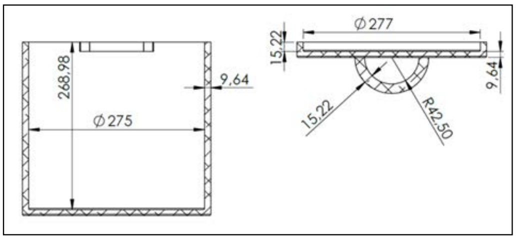
Handling Thimbles

$$s{:}r = 45mmt = 10mm$$

$$V_{em} = \pi\frac{t^2}{2}[2r + t] = V_{em} = \pi\frac{10^2}{2}[2 \times 45 + 10] = 15707.96mm^3$$

Calculation of Pattern Dimensions

The pattern cooking pot is made of mahogany wood (Figure 13). It has special properties, it is resistant to the pressure of compaction and easy for the realization.



(a)

(b)

Figure 13.Dimensions of the model cooking pot and its mahogany cover and their isometric views

Shrinkage Allowance

In our calculation, the shrinkage allowance of aluminum and its alloys is S_r=1.5%=0.015.

Choice of Machining Allowance

According to the ISO 8062, which precisely defines the dimensional tolerances, the typical Class of specified machining allowance is F to H see appendix 5 Table A2, and the Molding Tolerance Class is 10 to 13 see annex 5 table A1. The largest dimension is, therefore, the machining allowance (D_e = 269mm RMA = 2.5mms see appendix 5 table A3).

Body model; e_m = 9.64mm D_im = 275mm ; D_em = 294.28mm

Cover model; ; ; e_c m = 9.64mm d_i m = 277mm d_e m = 296.28mm h_im=15.225mm $V_{(c\_pattern)}$ = 797004.64mm^3.

Model of handling terminals; r_m = 42.5mm t = 15.22mm $V_{cm\text{-}pattern}$ = 36467.29mm^3

Sizing of Pouring and Feeding Systems

For the risers, we will break down the pot into 03 parts: body, lid, and pod.

Cooling module (Mr)

Body : $M_{r\_body} = \frac{1340913.82}{600047.34} = 0.223cm$

Lid: $M_{r\_lid} = \frac{339790.34}{155131.85} = 0.219cm$

Handling pod: $M_{r\_pod} = \frac{17707.96}{6483.19} = 0.242cm$

$$M_{r\_lid} < M_{r\_body} < M_{r\_pod}$$

If the weight is used to prevent the risk of shrinkage, it is the 03 terminals that must be weighted.

The volume of the riser:

$$\leftrightarrow V_{riser} \geq r.V_{part}.k5.5(0.01) \quad (53123.88)(6) \geq 17530.88mm^3$$

Riser module

$$M_{riser} \geq 1.2M_r = 1.2(2.42) \geq 2.9mm$$

Riser Dimensions

We will use the cylindrical-shaped flyweight

$V_{riser} = \frac{\pi}{4}D^2H$, but, $H = 1.5D$, hence, $V_{riser} = \frac{1.5\pi}{4}D^3$,

$D = \sqrt[3]{\frac{4V_{weight}}{1.5\pi}} = \sqrt[3]{\frac{4(17530.88)}{1.5\pi}} = 24.6mm$ and

$H = 1.5D = 1.5(24.6) = 36.9mm$

Solidification Time: Chvorinov's law $T_s = \beta\left(\frac{V_{pc}}{A_{pc}}\right)^n = 2.42^2 = 6\ secondes$

The Filling system is illustrated on Figure 14, and their parameters.[11,12]

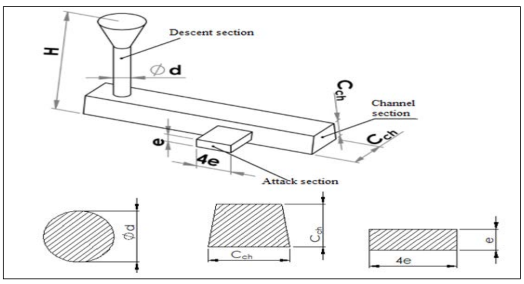


Figure 14.Characteristics of filing system

H : casting height; E : the thickness of the gating system section; d : diameter of the sprue section; C_{ch} : channel rating

Filling time (Tr): $1.4\sqrt{M} \leq t \leq 1.8\sqrt{M} \equiv T_r = 5.2s$

Metallo-static height; H_m (Casting drop height) The metallo-static height is not shown on the drawing of the cavity. But it is obtained by calculation according to the pour height (H) and the height of the cavity (C) and according to the type of pour, as shown in Figure 15.

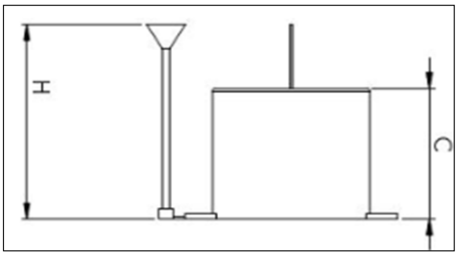


Figure 15.Characteristics for determining the metalol-static height

The pouring is from the bottom, we have:

$H_m = H - \frac{C}{2} = 400 - \frac{278.6}{2} = 260.69mm$

Mold print volume:

$V_{fil\ up} = V_{T\_pattern} + V_{riser} = 3899118.51mm^3$

Sprue section (with η pressure drop, annex 3):

$$S_d = \frac{\eta . V_{mould\ print}}{T_r\sqrt{2gH_m}} = \frac{0.4(4453750.88)}{5.2\sqrt{2(9.81\times1000)(260.9)}} = 151.42mm^2$$

$$d = 2\sqrt{\frac{S_d}{\pi}} = 2\sqrt{\frac{151.42}{\pi}} = 13.88 \cong 14mm$$

An abacus gives the scale according to the materials cast (See appendix 4), which is 1:1.2:2 for $\frac{S_d}{S_d} = 1$; $\frac{S_c}{S_d} = 1.2$, and $\frac{S_a}{S_d} = 2$, *respectively.*

Channel section: S_C = $S_c = 1.2S_d = 181.7mm^2$

Channel rating: C_{ch} = $\sqrt{S_c} = 13.48mm$

Gating system sections: $S_a = 2S_d = 302.84mm^2$

Gating system dimensions $l = 4e$ *et* $e = \sqrt{\frac{302.84}{4}} = 8.7mm$ *and the length* l *= 34.8mm*

As we have two gating systems sections, the dimension of a gating system is Section of a gating system S_a = 151.42mm², e = 6.15mm et l =24.61mm

Table 6.Pouring system synthesis[8]

Characteristics	Values
Staggering	1:1.2:2
Downhill section **Sd** (mm²)	151.42
channel section **Sc** (mm²)	181.7
Rating of a channel (mm)	13.48
Gating systems section **Sa** (mm²)	302.84
Section of a gating system (mm²)	151.29
Descent diameter **d** (mm)	14
Gating system thickness dimension **e** (mm)	6.15
The width dimension of a gating system **L** (mm)	24.61

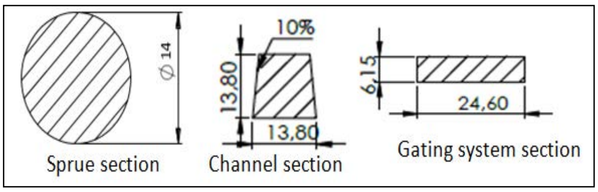


Figure 16.Different pouring sections

Table 6, summarizes the parameters of the pouring system and their respective sections in Figure 16.

The height of the channel is greater than that of the gating system to limit the entry of dirt (sand, oxides, ..) into the footprint by density difference.

Supply of raw materials needed for molding

Top frame sand volume: 750×750×400-4453750.88 = 220.546dm³

Lower frame sand volume: 750×750×160 =90dm³

Mass of sand: 276.79×1.6 =496.86kg

Water volume = 5 x 210/100 = 24.8 liters (for the choice of water percentage see annex 6). The chosen value is 5%.

Quantity of aluminum: $4453750.88 \times \frac{2700}{10^9} = 12kg$

Figure 17 to 19, gives us the details on the constituent parts of the mold and the cover handle molding is explained latter.

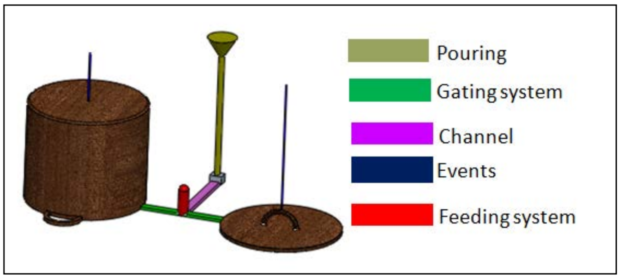


Figure 17.Casting cluster

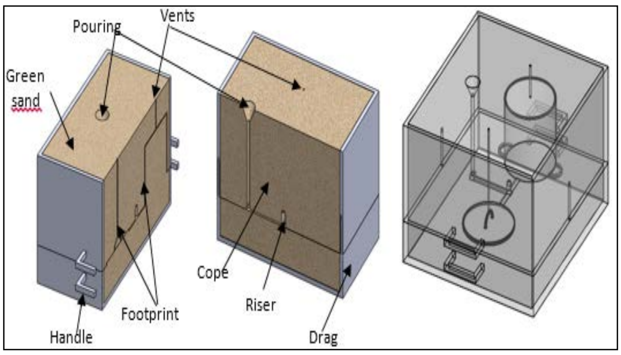


Figure 18.Cut-away moldand transparency view

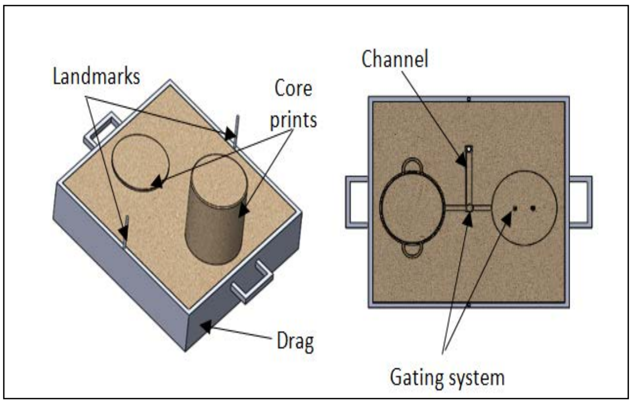


Figure 19.Different parts of the mold

Calculation of the metering

M_1=4715.41g mass of the final pot

M_2=12000g mass of the pot before unhooking

$$M_{mil} = \frac{M_2}{M_1} = \frac{12000}{4715.41} = 2.54$$

The goal of metering is to minimize the loss of raw material.

Proposal 2: Casting of the cover only

Figure 20, illustrates the nominal and model dimensions of the cover.

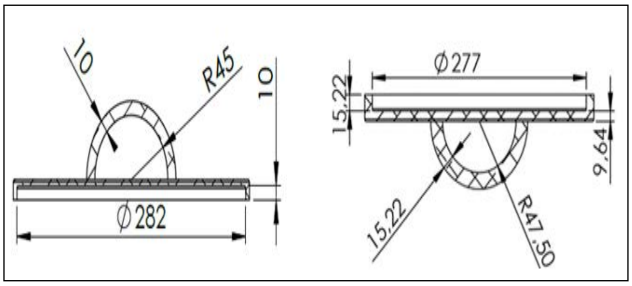


Figure 20.2D drawing of nominal and model of cover

Top Pouring: pressure drop (appendix 3); 0.7 metallo-static height; t =H_m= H = 100; Section of sprue is = 173.55mm^2 and the diameter of the section is 15mm. Table 7 summarizes the lid sizing parameters and the Figure 21, illustrates 2D drawing description.

Table 7.Cover molding

Lid	
Characteristics	**Values**
Frame dimensions	315×315×100mm
Amount of sand	31.7kg
Amount of water	1.58 liters
Footprint volume	833471.93mm^3
Aluminum quantity	2.25kg
Pouring time	2.4 secondes
Sprue section	173.55mm^2
Diameter of sprue section	15mm

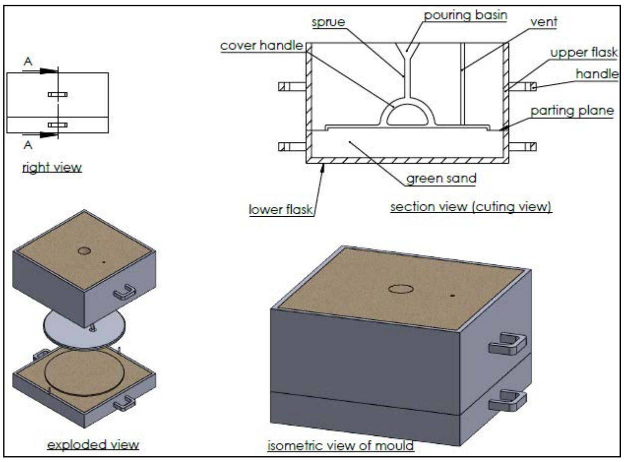


Figure 21.2D drawing of the cover

Realization of the Cover Handle

In general, the handle of the lid of the pot is of several forms. The most common form is that of a half-circle. In the case of our study we will use a round model (semi-circle). The model is in two parts to facilitate its removal during the realization of the impression. So the model is made of two half circles and each half circle is a 1/4 of the circle. In addition to the added allowances (machining and shrinkage). To facilitate the extraction of the model from the sand without deterioration (removal) of the sand it is necessary to provide a draft angle of 5° degree. The draft analysis on the model of the lid handle is shown in the Figure 22.

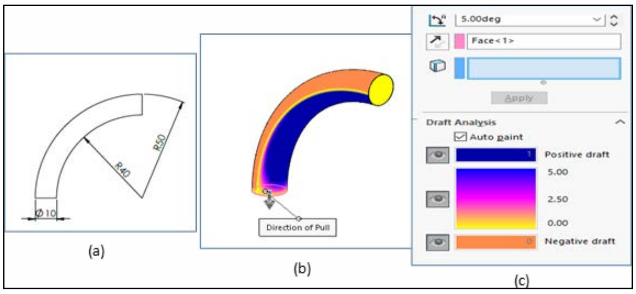


Figure 22.Drafting analysis of the handle half on Solid Works

It is absolutely necessary to divide the model of the handle in two because the ejection of the model during the realization of the impression would be impossible, because when the model is not divided in two, the negative draft is on both sides, prohibiting a direct demolding of the model during the realization of the impression.

The draft or draft angle is the inclination of the mold walls necessary to facilitate the demolding of the part. It is called undercut when the shape of the part prohibits a direct demolding. A positive draft angle reduces friction during demolding (when the part is extracted or ejected). If the draft angle is too small, more pressure must be exerted to eject the part and there is a risk of damaging the two opposing surfaces. Only the faces parallel to the demolding direction are concerned, where there is a risk of adhesion between the part (and the pattern when making the model) and the mold.

Cluster Lids Molding

Table 8, summarizes the sizing parameters of the cluster casting and its 3D model, as shown in Figure 19.

Table 8.Cluster molding

Characteristics	Values and units
frame dimensions	(630×315×160 mm)×3
Amount of sand	152.4kg
Amount of water	7.62 liters
Aluminum quantity	9kg
Pouring system	
pouring time	5 secondes
Sprue section	150mm²
Section diameter	14mm
Staging	1-1.2-2
Gating system section	300mm²
Number of gating system	4 gatings
Dimensions of gating system	h=4mm et l=16mm

Cluster molding allows multiple lids to be molded in a single filling in clustered cavities. The mold consists of three (03) parts with a total of four (04) lid cavities connected by a filling shaft.

The making of the pattern footprint is similar to the making of a single lid casting, except for the making of the filling system. There are two steps to making the footprints: the pattern is placed in the sand to obtain the footprint (Figure 23) and then the casting cluster is removed from the sand to obtain the final footprint (Figures 24 and 25).

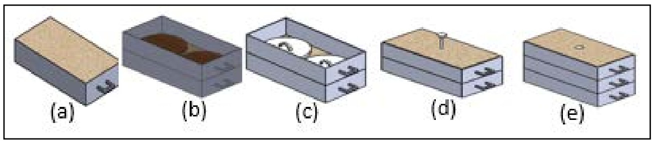


Figure 23. Process of obtaining the impression of the cover and handle pattern: filling the lower part (a), placing the model of two covers (b), placing the two half handles of the cover (c), filling the middle frame (d), tamping the filling, repeating steps (b) and placing the upper frame (c), filling the upper frame (e)

The principle is the reverse of the previous principle to eject the casting cluster from the sand to obtain the final footprint. The filling system, the upper part of the mold along the vertical axis, the model of the wrist of the lower part of the upper mold should be removed. Then, we remove the model of the cover of the upper part of the intermediate mold and also the intermediate part of the mold. Finally, the model of the wrist of the lower part of the intermediate mold and the model of the cover of the upper part of the lower mold are removed.

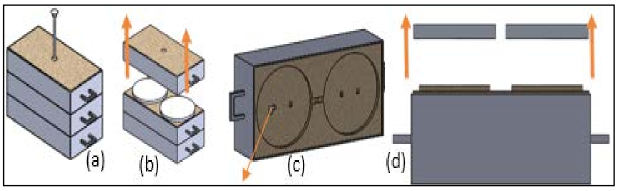


Figure 24.Details of the process of obtaining the final impression of the cover and handle: Removal of the filling system(a)Removal of the top frame(b) Removal of the pattern cover handle halves(c) Removal of the cover pattern(d)

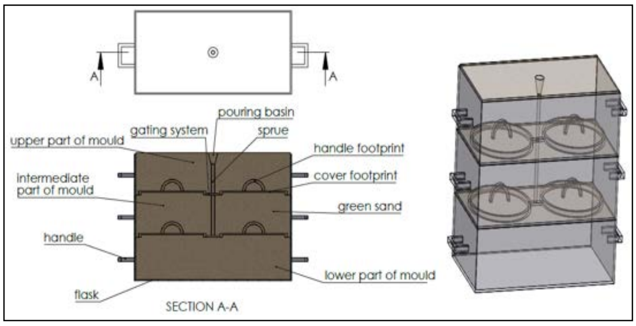


Figure 25.Isometric and 2D drawing of cluster mussel

It can therefore be seen that the cluster molding of the lids makes it possible to reduce the setting to the thousandth and the saving in time. The molding of the cover alone makes it possible to obtain several covers in one step.

Proposal 3: Molding of the "does everything" pot of particular shape.

Figure 26, shows the pot to obtain and its pattern and also the nominal dimensions.

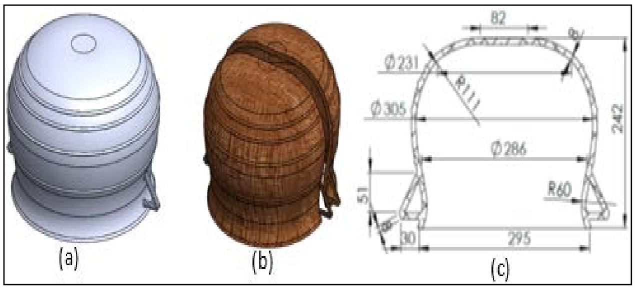


Figure 26.Pot to obtain(a) wooden pot pattern(b) and 2D drawing of pot dimensions(c)

The model dimensions are obtained, taking into account the machining and shrinkage allowance by following the same procedure as for the cylindrical pot. According to annexes 2 and 5, we have RMA = 2.5mm the widest dimension is 305mm and the machining allowance is S_r = 1.5% = 0.015mm.

Sizing of the Filling and Feeding System

Volume of the pot: and the Surface area: *V_T=2106905.38mm^3 A=534310.51mm^2*

Mass: and the Volume of the model: *M=5688.64g $V_{modèle}$ = 3516177.72mm^3*

Feeding system [2]

Cooling module $M_r = \frac{V_T}{A} = \frac{2106905.38}{534310.51} = mm = 0.62cm$

Solidification time: $T_s = \left(\frac{V_T}{A}\right)^2 = M_r^2 = 6.2^2 = 38\ secondes$

Riser module: M_{weight} = 1.2(0.245) = 0.744cm

Riser volume: V_{weight} = 5.5(0.01)(6)(332416.65) = 695278.77mm^3

Dimensions of the Riser:

Riser diameter: D_{mas} = 5.M_{mas} D_{mas} = 5(6.2) = 37.5mm

Riser height: = 75mm H_{mas} = 2D_{mas}

Filling System[2]

Volume to be filled: $V_{fil\ up} = V_{pattern} + V_{riser}$ = 4211456.5mm^3

Drop height: $H = 320 - \frac{248}{2} = 196mm$

Charging time: T_r = 2 secondes

Sprue section: $S_d = \frac{\eta . V_{remplir}}{T_r\sqrt{2gH_m}} = \frac{0.4(4211456.5)}{2\sqrt{2(9.81\times1000)(196)}} = 172mm^2$

Hence, $d = 2\sqrt{\frac{S_d}{\pi}} = 2\sqrt{\frac{172}{\pi}} = 14.7mm$

Channel section: $S_c = 3S_d = 516mm^2$

Section of a channel: $S_c = 258mm^2$

Channel dimension: $C_{ch} = 16mm$

Gating system section: $S_a = 3S_d = 516mm^2$

Dimension of getting system or a channel: Section of gating system *S_a = 258mm^2 hence, e = 8 mm and the length l = 32mm*

Supply of Raw Materials Needed for Molding

Sand

volume of sand = 400×450×350 = 63dm^3

mass of sand M = 63×1.6 = 100.8kg

amount of water needed for the mixture= $100.8 \times \frac{4}{100} = 4.032\ liters$

Aluminum quantity of aluminium= $4211456.5 \times \frac{2700}{10^9} = 11.37kg$

Controlling the amount of water for mixing the sand is important, as the sand that is too wet can cause risks: false tightening, gluing, risk of metal backflow, splashing, faults due to excess gas such as bites, blowholes.

Figure 27, shows the different parts and the isometric view of the mold.

Figure 28, Shows that a mold ready for filling is derived from the model part leaving its impressions. Therefore, it can be concluded that a good dimensioning of the constituent elements of the cluster and their placement (construction of the cluster) is the first step towards the success of the molding process.

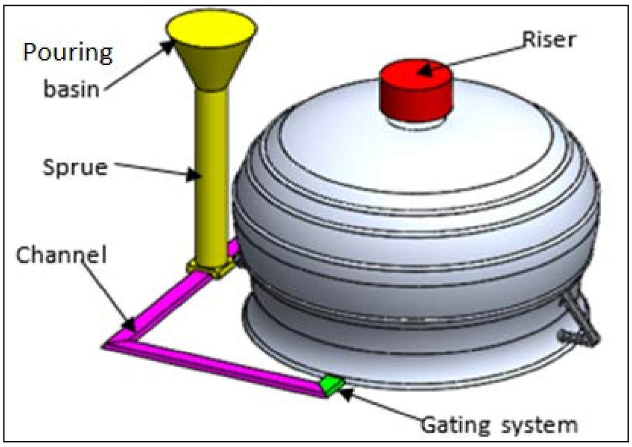


Figure 27.Mold details

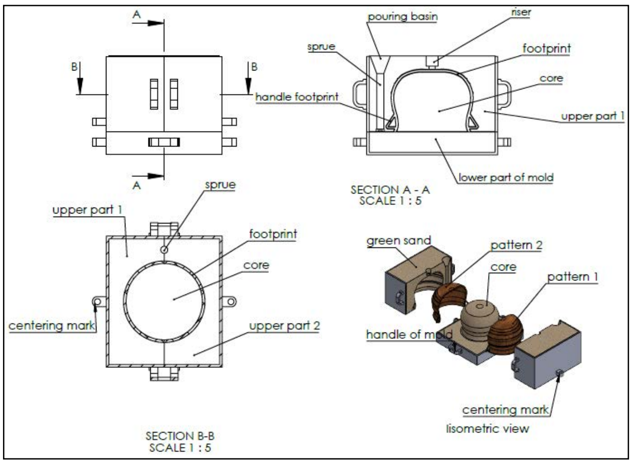


Figure 28.2D and exploded view of the mold close to casting

Conclusion and Perspectives

The success of a pot depends on the application and control of molding variables which are basic engineering principles. Good mold design and sizing is the critical success of a molding process, even in artisanal molding, where subjective foundry experiences dominate. This is why we insist on respecting the different sizing steps proposed above for hand molding of recycled aluminum pots. The sizing that we have proposed makes it possible to know the fundamental molding prerequisites: the design of the mold, particularly the riser, the ladle, the downspouts, channel, and gating system sections, as well as their positions, the parting line.

However, sizing of the mold alone is not sufficient for the success of a molding process; non-negligible parameters such as the formulation of the molding sand mixture, the purification of the aluminum, which concerns health, and the design of a furnace for the smelting of aluminum.

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Appendices

Appendix 1.Choice of value for (volumetric shrinkage of the riser)

Alloy		Values are taken into account to produce liquid alloy supply systems in %
Aluminum alloys	and copper	7 to 8
	and Magnesium	7 to 8
	and Silicon	3.5 to 5
	and Zinc	8
Copper alloys	Cupro-aluminum	4
	Bronzes	4.5
	Brass	6.5
	High strength brass	7.5
Ferrous alloys	Unalloyed cast steels	5 to 7
	Cast alloy steels	7 to 10
	GL cast iron	0.5 to 3
	GS cast iron	3 to 6
	Allied cast iron	6 to 8
Magnesium alloys		4
Zinc alloys		5

Appendix 2.Metal shrinkage allowance

Alloy		Values are taken into account to produce the mold tooling (%)
Aluminum alloys	and copper	1.2 to 1.4
	and Magnesium	1.2 to 1.4
	and Silicon	1.1 to 1.3
	and Zinc	1.5
Copper alloys	Cupro-aluminum	1.8
	Bronzes	1.2 to 1.4
	Brass	1.5
	High strength brass	1.7
Ferrous alloys	Unalloyed cast steels	2 to 2.4
	Cast alloy steels	2.2 to 2.4
	GL cast iron	0.5 to 1.2
	GS cast iron	1 to 1.7
	Allied cast iron	1.5 to 2
Magnesium alloys		5
Zinc alloys		0.4 to 0.5

Appendix 3.Pressure drop depending on the type of casting

Cast from above	0.7
Casting from the side	0.4
Bottom casting	0.4
The casting of flat parts	0.25

Appendix 4.Phasing table for the calculation of the different filling sections

	S_d/S_d	S_c/S_d	S_a/S_d
Aluminum	1	2	1
	1	1.2	2
	1	2	4
	1	3	3
	1	4	4
	1	6	6
Aluminum bronze	1	2.88	4.8
Brass	1	1	1
	1	1	3
	1.6	1.3	1
Copper	2	8	1
	3	9	1
Ductile iron	1.15	1.1	1
	1.25	1.13	1
	1.33	2.67	1
Grey cast iron	1	1.3	1.1
	1	4	4
	1.4	1.2	1
	2	1.5	1
	2	1.8	1
	2	3	1
	4	3	1
Magnesium	1	2	2
	1	4	4
Malleable iron	1	2	9.5
	1.5	1	2.5
	2	1	4.9
	1	1	7
Steels	1	2	1
	1	2	1.5
	1	2	2
	1	3	3
	1.6	1.3	1

Appendix 5.ISO 8062 standard dated 01-04-1994

Table A1.Tolerance class

Type of molding	Tolerance class								
	Casting metals and alloys								
	Steel	Grey font	Spheroidal graphite cast iron	Malleable cast iron	Copper alloy	Zinc alloy	Alloys light metals	Nickel base alloys	Cobalt-based alloys
Hand sand casting	11 to 14	11 to 14	11 to 14	11 to 14	10 to 13	10 to 13	9 to 12	11 to 14	11 to 14
Sand casting Mechanical and shell casing	8 to 12	8 to 12	8 to 12	8 to 12	8 to 10	8 to 10	7 to 9	8 to 12	8 to 12
Shell molding by gravity / low pressure	Work is in progress to refine the appropriate values. Consultations should take place between the modeler and the client to agree on the data to be used.								
Die-casting die-casting									
Precision casting									

Table A2.Typical class of specified machining allowance

Type of molding			Class of specified machining allowance						
			Casting metals and alloys						
	Steel	Grey font	Spheroidal graphite cast iron	Malleable cast iron	Copper alloy	Zinc alloy	Alloys light metals	Nickel base alloys	Cobalt-based alloys
Hand sand casting	G to K	F to H	F to H	F to H	F to H	F to H	F to H	G to K	G to K
Sand casting Mechanical and shell molding	F to H	E to G	E to G	E to G	E to G	E to G	E to G	F to H	F to H
Gravity / low-pressure shell molding	-	D to F	D to F	D to F	D to F	D to F	D to F	-	-
Die-casting die-casting	-	-	-	-	B to D	B to D	B to D	-	-
Precision casting	E	E	E	-	E	-	E	E	E

Table A3.Selection of the allowance according to the most considerable dimension

Machining allowance											
Largest dimension (mm)		Class of specified machining allowances									
Above	Up to and y understood	AT	B	VS	D	E	F	G	H	J	K
-	40	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.7	1	1.4
40	63	0.1	0.2	0.3	0.3	0.4	0.5	0.7	1	1.4	2
63	100	0.2	0.3	0.4	0.5	0.7	1	1.4	2	2.8	4
100	160	0.3	0.4	0.5	0.8	1.1	1.5	2.2	3	4	6
160	250	0.3	0.5	0.7	1	1.4	2	2.8	4	5.5	8
250	400	0.4	0.7	0.9	1.3	1.8	2.5	3.5	5	7	10
400	630	0.5	0.8	1.1	1.5	2.2	3	4	6	9	12
630	1000	0.6	0.9	1.2	1.8	2.5	3.5	5	7	10	14
1000	1600	0.7	1	1.4	2	2.8	4	5.5	8	11	16
1600	2500	0.8	1.1	1.6	2.2	3.2	4.5	6	9	13	18
2500	4000	0.9	1.3	1.8	2.5	3.5	5	7	10	14	20
4000	6300	1	1.4	2	2.8	4	5.5	8	11	16	22
6300	10,000	1.1	1.5	2.2	3	4.5	6	9	12	17	24
The largest dimension is that of the machined blank											

Appendix 6.The mixture of moulding sand

Casting sand	Composition %				properties		
	Sand unchecked	Quartz sand	Sand (bentonite)	addictions	Moisture %	Permeability	Resistance to compression in wet condition (Kgf/cm²)
Single sand	85-90	Molding from 10-5	Cast iron 3 (1-0.5)	1-sulfuric detergent 0.5-Coal	4-5	70-80	0.4-0.6
sand contact	50-60	40-30	6.5-5.0 (2-1.5)	2-sulfuric detergent 3-Coal	4.5-5.5	80-100	0.5-0.6
Sable de remplissage	96-98	3-45	1.0-0.5	----------	5-5.5	60	0.3-0.4
unique high resistance sand (for the automatic machine)	93-96	3.5-2	--------- (2-1.5)	1-Coal 0.5-starch	3-3.4	120-150	1.5-1.7
unique sand for aluminum alloys	82-87	10-5	10-8	---------	4.5-5.5	20	0.3-0.5
Unique sand for bronze	80-85	10-5	12-8	1.5-Coal	4.5-5.5	30	0.3-0.5