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Design and Construction from Local Materials of an Aluminum Recycling Foundry

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ABSTRACT: In the low-carbon global aluminum cycle actual perspective, the need of remelting aluminum is in constant increase. The objective of this work was to build a portable aluminum foundry based on local materials. This foundry can be used to make small spare parts in complete safety and/or as practical melting equipment. The foundry is made up of a butane combustion Furnace and various tools for handling molten aluminum. The Furnace was manufactured by recycling a defective gas cylinder. After removing the top of the bottle, we lined the inside with a layer of local clay which serves as a 5-centimeter thermal insulator. The crucible was made by recycling a waste hermetic compressor, and the tools by recycling scrap metal. The tests carried out allowed to melt used cans and other parts of motorbikes and cars defective in aluminum. Liquid aluminum was cast to obtain cylindrical and prismatic blanks for machining, as well as other small mechanical parts. The cost of carrying out the project has been estimated at nearly 150,000 XAF.

KEYWORDS: Aluminum recycling, Design and production, Foundry, Local materials, Manufacture of spare parts.

1. INTRODUCTION

Designing and building an aluminum recycling foundry using locally available materials represents a significant effort in sustainable manufacturing and resource use. This initiative aims to create a facility capable of efficiently recycling scrap aluminum into high-quality materials suitable for manufacturing spare parts. By leveraging local resources, this project not only promotes economic efficiency, but also reduces environmental impact through the sustainable reuse of materials. Aluminum is a versatile metal widely used in various industries due to its light weight, corrosion resistance and mechanical properties. However, its production from primary sources consumes a lot of energy and generates greenhouse gas emissions. Aluminum recycling, on the other hand, requires much less energy – around 95% less than primary production – making it a crucial aspect of sustainable industrial practices. The design and construction of a mini aluminum recycling foundry represents a significant step forward towards sustainability and responsible resource management. Indeed, aluminum is one of the most widely used materials in the modern world, but its primary production consumes enormous amounts of energy and generates significant greenhouse gas emissions. This is where the recycling foundry comes in, a solution that permit to recover and reuse aluminum from various waste. This mini foundry is designed to operate efficiently and sustainably, using modern metal melting and processing techniques. The process begins with the collection of aluminum waste, such as packaging, cans and manufacturing scraps. These materials are then sorted, cleaned and melted at high temperatures in a furnace specially designed for aluminum melting. Once melted, the aluminum is purified to remove impurities and then cast into ingots or specific shapes for reuse in new applications. Besides the obvious environmental benefits, such as reduced waste and CO2 emissions, a mini aluminum recycling melter also has economic benefits. It can provide a cheaper source of raw material compared to virgin aluminum, while creating local opportunities for employment and technological development.

2. LITERATURE REVIEW

2.1. Foundry

Definition. Foundry derived from melting is one of the metals forming processes that consists of pouring a metal or liquid alloy into a mold to reproduce a given part (interior and exterior shape) after cooling, limiting as much as possible the subsequent finishing work.

General. In a foundry, different parts are produced after the metal has been melted. The metal is heated to a high temperature to produce liquid metal that is then poured into a mold to take on the desired shape before it cools and solidifies. This makes the furnace and a mold of the elements essential to the foundry. Indeed, once in the mold, the liquid metal will take shape by acquiring all its physical, mechanical and chemical properties. As for the quality, it will depend essentially on the quality of the alloys made by the fusion of metals, as well as on the conditions of production **[1]**. It should also be noted that it is part of the metallurgy field, along with forging and boilermaking.

The different stages of the formation of a metal part.

These steps can be summarized in a few lines, including:

- Smelting and metal processing: the smelting workshop
- Preparation of molds and cores: the molding workshop
- Casting of the molten metal in the mould, cooling for solidification and demoulding: the casting workshop
- Finishing of the raw molded product: the finishing workshop.

2.2. Furnace

A furnace is a refractory-lined vessel that contains the material to be melted and provides the energy needed to melt it.

Types of Furnaces. There are several types of furnaces depending on the energy source and the material to be melted. The most commonly used furnaces include: crucible furnaces, cupola furnaces, induction furnaces, and electric arc furnaces **[2]**.

Crucible furnace. These furnaces use a crucible (refractory or an element that resists the melting temperature of the metal) that contains the metal charge. The charge is heated by heat conduction through the walls of the crucible.

Heating fuel is usually coke, oil, gas or electricity.

Cupola. The cupola is a vertical furnace for melting metals by burning coke. In this furnace, the metal to be melted is usually scrap metal and is in direct contact with the fuel. The size of a cupola is expressed in diameter and can vary from 450 mm to 2000 mm. There are 3 types of cupolas: hot wind cupola and long country cupola (which can be cold or hot wind).

Electric arc furnace. It is a furnace that uses the thermal energy of the electric arc established between one or more carbon electrodes and the metal to obtain a sufficient temperature for its melting. It can melt from small quantities (1 ton) to large quantities (400 tons). It is mainly used to melt steel. The temperature generated by the arc exceeds 1800°C and can reach 3600°C. Energy consumption ranges from 500 to 800 kWh/tonne of molten steel, depending on the capacity of the hot metal consumption, and the refining techniques, tapping temperature and the equipment used for pollution reduction.

Induction Furnace. There are used to melt both ferrous and non-ferrous metals. There are several types of induction Furnaces available, but all of them work by using a powerful magnetic field created by the passage of an electric current through a coil wrapped around the Furnace. The magnetic field in turn creates a voltage, and therefore an electric current, through the metal that needs to be melted **[3]**.

2.3. Casting

It consists of making raw parts by casting the molten metal in a sand or metal mold (representing the imprint of the part to be obtained), the metal solidifying, reproducing the contours and dimensions of the mold indentation. It is generally the raw parts that are obtained by this process. The melting temperature of the material to be poured must be lower than the melting temperature of the mold material.

2.4. Aluminium

Aluminium is a silvery-white metal, the 13th element of the periodic table. Aluminium is the most common metal on earth and represents 8% of the earth's central mass. It is also the third most common chemical element after oxygen and silicon **[4]**. Because of its reactivity, pure aluminium does not occur in nature and the most common form is aluminium sulphate and can be found in more than 270 other minerals. Aluminium is a good conductor of heat and electricity with a low density of 2.7 kg/dm^3. Melting point: 658°C. It is also the most used metal after iron, it is found in household utensils, packaging, cans, automobiles, trains and planes **[5][6]**.

Figure 1 shows some aluminium final products.

As Figure 2 shows, in 2020 39.2 % (40 Mt) of casted aluminium in the world was a remelted one vs 60.8% (66Mt) of primary aluminium from alumina. Part of this 40Mt of remelted aluminium is a 12 Mt of final products scrap vs 8.3Mt in 2007 **[7]**.

Figure 1: Engine housing and food-grade aluminum rollers

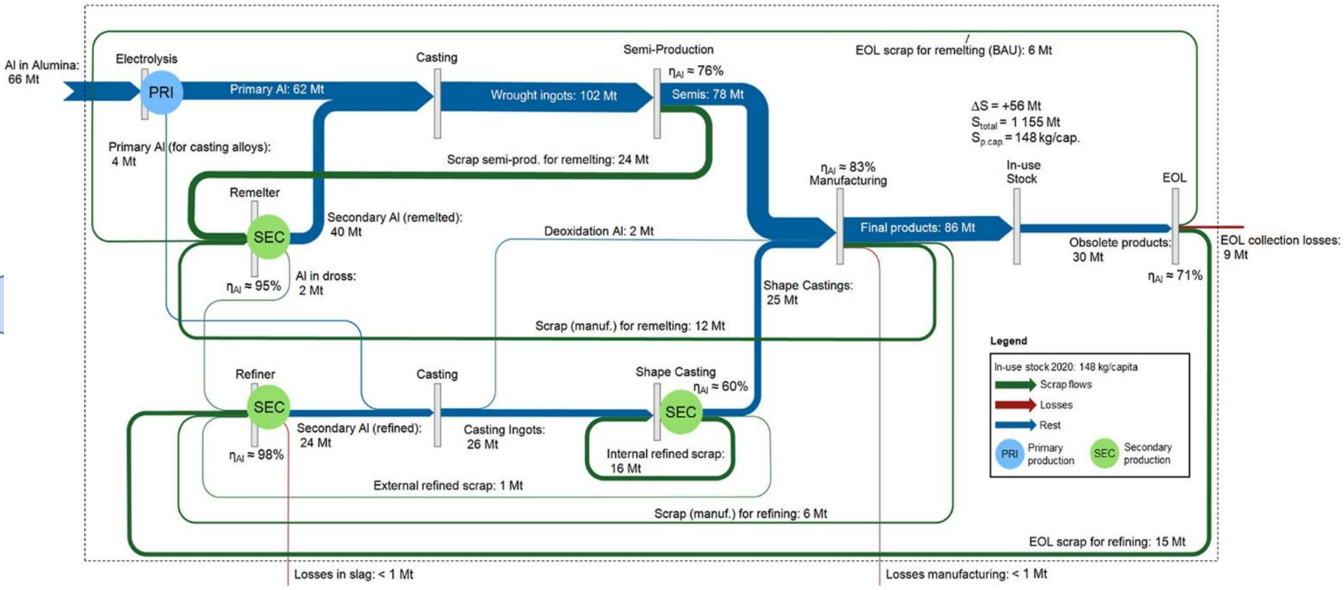


Figure 2: Global aluminum cycle in 2020 [8]

The scrap from final products is projected to reach 21Mt for remelting according to the 2050-reference demand & business-as-usual **[8]**, meaning that the need of remelting aluminium is in constant increase.

3. MATERIAL AND METHODS

3.1. Material

Field equipment. We have carried out several decent on different sites. And for this, we have prepared a questionnaire to know the state of the foundries that we find in the city of Ngaoundere.

Field Questionnaire Sheet

- What type of Furnace do you use?
- What material could you melt?
- How high is your Furnace going?
- What insulation material do you use in your Furnace?
- What are the foundry accessories you use?
- How do you melt aluminum?
- What safety measures are useful in your foundry?
- How much material can your crucible hold?
- What materials is your crucible made of?
- What type of sand do you use to mold?
- Which part can you mold?
- What is the Furnace made of?

Equipment used in the study. To carry out our study we used a number of materials such as:

Computer. It is an automatic and rational information processing machine. The one we used is a DELL brand.

Smart phone. Also known as a smartphone, it is a mobile phone with advanced functionalities similar to those of a computer. The one we used is a TECNO brand.

SolidWorks software. SolidWorks software is a computer-aided design (CAD) software. It is a volume modeler for creating complex 3-dimensional parts. We used this software to model our models that we studied. We also brought out the overall drawings of the implemented model.

3.2. Methods

Functional analysis of the product: This is an approach that consists of researching and characterizing the functions offered by a product to satisfy the needs of its user. Its approach is as follows **[9], [10], [11], [12]**.

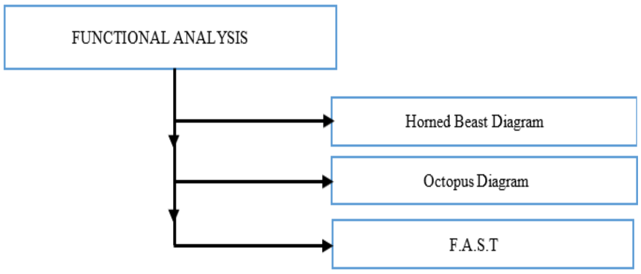


Figure 3: Functional and Structural Analysis Model

Horned Beast Diagram: This tool defines the need that the system addresses. We used this tool to clearly identify our needs. To do this, it is essential to ask yourself the following three questions:

- To whom, what does the product serve?
- On what, on what does it act?
- For what purpose? (Why do that?)

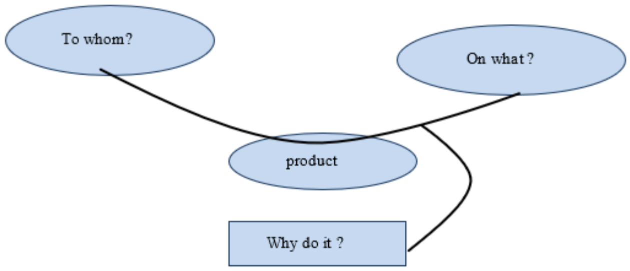


Figure 4: Horned Beast Diagram

Octopus diagram. This tool identifies the functions of a system or product, looks for the expected functions and their relationships in the functional analysis of the need (or external functional analysis). With the help of this tool, we have brought out the main function of our Furnace, i.e. the reasons why the object was created, the elements of the external environment with the constraints that the object must satisfy.

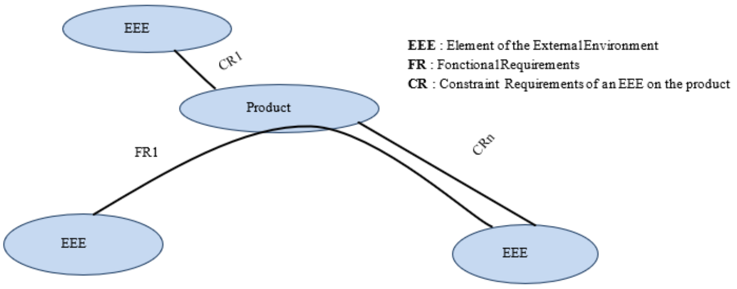


Figure 5: Octopus diagram

F.A.S.T. diagram Functional Analysis System Technic presents a rigorous translation of each of the service functions into technical function(s), and then materially into constructive solution(s). The F.A.S.T. is built from left to right by answering the questions How and When? It is shown in figure 6.

General drawing. In technical drawing, an overall drawing is the representation of a complete (or partial) mechanism that allows each of the parts that make it up to be located. The parts are designed, on a scale depending on the actual dimensions of the mechanism and the sheet containing the design, in their exact position (assembled), which allows us to get a concrete idea of how the mechanism works. An overall drawing is most often accompanied by a nomenclature proposing a designation of each part, its material, its number of occurrences, its production process and possibly internal information of the company. Using the SolidWorks software, we brought out our overall drawing which allowed the assembly of our Furnace.

Cost of production. The cost of production of a business or government is the sum of the expenses incurred to produce goods or services. This cost is made up of the direct and indirect costs of production. To get the manufacturing costs of our Furnace, we made several decent ones in the hardware stores in the city. This allowed us to obtain the prices of the materials.

4. RESULTS AND DISCUSSION

4.1. Functional Structural Analysis

Aluminum foundry Horned Beast Diagram:

Thanks to our horned beast tool, we were able to clearly establish the user's need to shape the aluminium after melting it with the help of the Furnace. It is shown in figure 7.

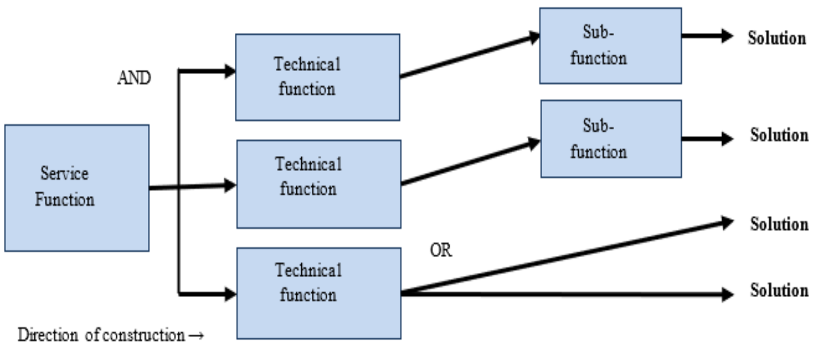


Figure 6: F.A.S.T. diagram

Decision matrix. It is more difficult to make decisions when faced with complex choices that involve many variables. Thanks to this tool, we decided which model to make by listing all our choices in a table and methodically evaluating them according to certain criteria.

Aluminum foundry Octopus diagram:

This tool brought out the functions of our product, including a major function which is the shaping of aluminum and a minor one which is to melt aluminum. It is shown in figure 8.

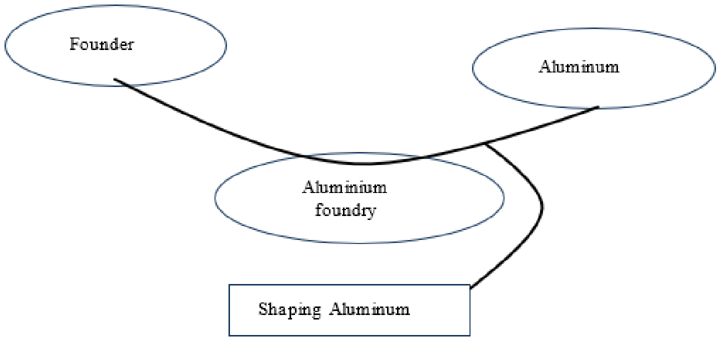


Figure 7: Horned beast from an aluminum foundry

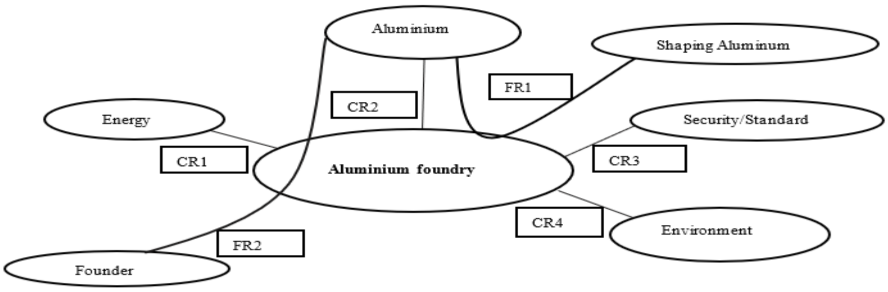


Figure 8: Octopus diagram of an aluminum foundry

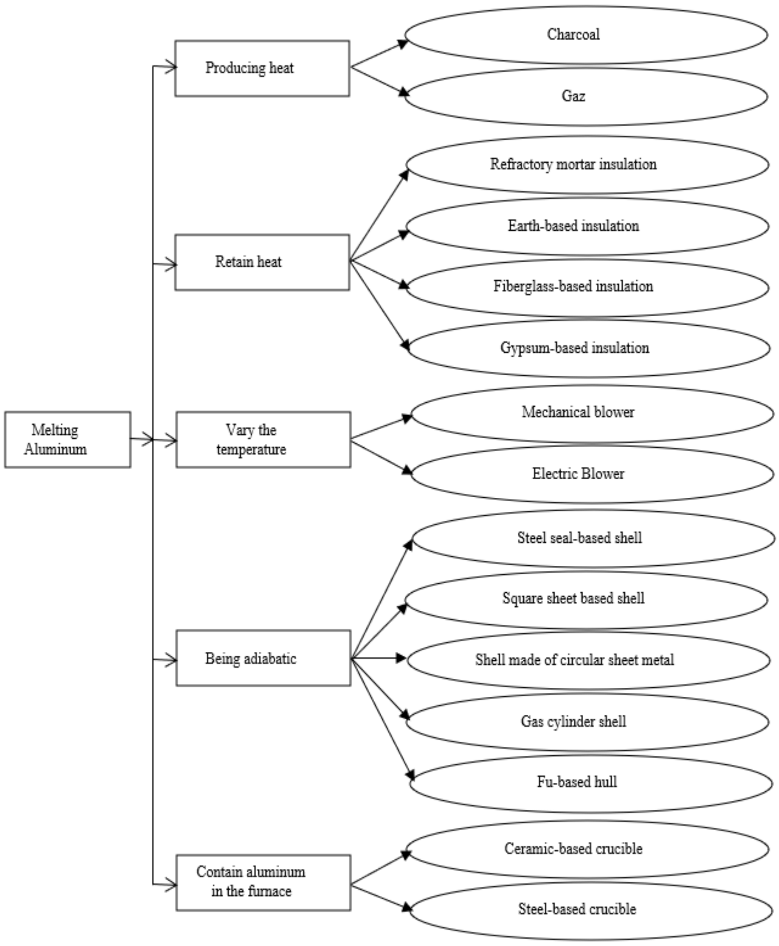


Figure 9: F.A.S.T. diagram of the aluminum melting subfunction

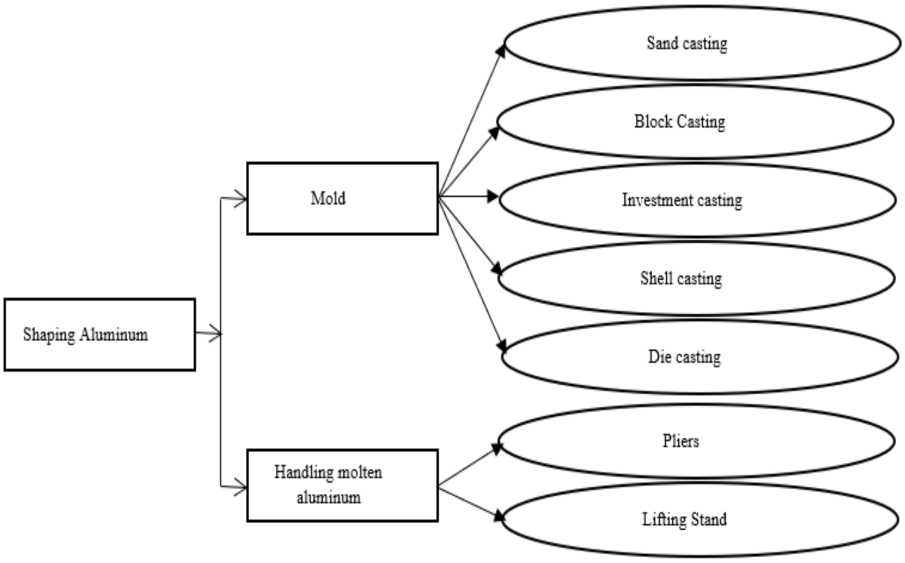


Figure 10: F.A.S.T. Diagram of the Shaping Aluminum Function

Main functions:
FR1: Melt aluminium
FR2: Shape the aluminium

Constraint functions:
CR1: Supply energy
CR2: Sort aluminium to avoid other metals
CR3: Dry aluminium to avoid water droplets in waste
CR3: Comply with thermal safety standards and rules.
CR4: Be in a ventilated place

Aluminum foundry F.A.S.T Diagram:
These F.A.S.T. models, obtained from the main function of shaping aluminium and the subfunction of melting aluminium, allowed us to obtain different solutions for our furnace that we implemented. They are shown in figures 9 and 10. As a technological solution chosen, we have:

➢ To produce heat, we used gas

➢ To contain the heat, we used an earth-based insulation (clay)

➢ Vary the temperature, we used an electric blower

➢ Contain the insulation, we used a shell based on the gas bottle

➢ Contain the aluminum in the furnace, we used a steel-based crucible

➢ Handle the molten aluminum, we used the clamp and lifting bracket

➢ Cast molten aluminum, we used sand casting

4.2. Different models study on SolidWorks
After having documentation on the subject and watching the videos on YouTube, we decided to design a portable crucible furnace. With the help of the SolidWorks software, we made 3 models and one was chosen.

Model 1: Sheet metal bent in a circular shape. This model is made from a sheet of sheet metal of 2.5mm thickness, 5mm flat iron, 40*40 square tube and circular tubes of diameter 60mm, 50mm and 30mm.

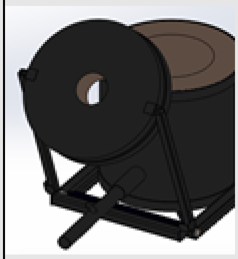
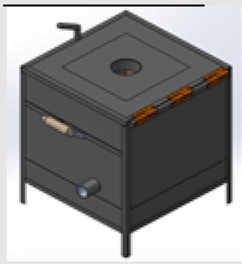
Model 2: angle iron and sheet metal. This model is made from sheet metal made of 2.5mm thick steel, 40mm angle iron and 4mm flat iron.

Model 3: Square tube gas cylinder. This model is made from a gas cylinder 3mm thick and 600mm high that is cut and then 40mm square tubes are added to make the opening system.
It is shown in table 1.

According to our decision matrix, our best choice and model 3. But when we went into the field to appropriate the equipment necessary for our construction, we noticed that by using the angles instead of the square tubes of 40 and flat iron, the Furnace comes back to us at a lower cost and its robustness does not change and it becomes simpler.
This made us move to the 3.1 model.

4.3. Project cost
The cost of building the foundry is determined in tables 2 below.
We spend around 150 000 XAF to realize our foundry elements.

Table 1. Decision matrix

				
	Choice Coefficient of importance	**Model 1**	**Model 2**	**Model 3**
Criterion		Note	Note	Note
Efficiency	5	4	2	4
Usable volume	4	3	4	3
Cost of implementation	5	3	2	4
Robustness	5	3	3	4
Simplicity to achieve	3	3	3	4
	Result	**71**	**60**	**84**
	Rank	2	3	1

4.4. Realization and testing of the aluminium foundry

The results of the construction and performance of the proposed aluminium foundry are shown in Figure 11 below. Image **a** of the figure present the furnace which is a butane gas one. On image **b**, all the elements of the foundry are exposed.

Beside the furnace, we have the blower, the butane gas pink bottle and three operating tools. Image **c** illustrates the supply of scrap cans in the crucible inside the furnace to be recycled during the melting test. Image **d** shows the liquid aluminium in the heated crucible inside the furnace, whereas image **e** shows the sand-casting operation. The parts obtained after demolding are presented on image **f**.

a - Furnace**; b** - Foundry elements**; c -** Supply of scrap cans in the crucible inside the furnace**; d -** Liquid aluminium in the heated crucible inside the furnace**; e -** Sand casting operation; **f -** Parts obtained.

Figure 11: Realization and testing of the aluminium foundry

Table 2. Cost of the foundry elements manufacturing

Materials	Quantity	Price (XAF)
Empty gas cylinder	1	21000
60 hoses	35cm	2000
Angle of 40	5,8	11700
12 mm diameter Reinforcing Bars	5,8	6200
Kaolin	50kg	2000
Clay	50kg	3000
Crucible (Refrigerator Compressor)	1	1000
Blower	1	16000
Burner	1	17000
13 Screw with Washer and Nut	2	500
Gas	1	6000
Pliers	1	1000
Aluminum Scrap	5kg	5500
White cement	1	4000
Sand for casting	25kg	4000
Transport	1	12000
Electricity cost	1	5000
Crucible (steel)	1	7000
Bag of charcoal	1	4000
Miscellaneous		18500
Total		**147 400**

5. CONCLUSION

At the end of this work, which focused on the design and construction of a foundry for remelting aluminium, we were able to build an operational one. After the testing process, the aluminum parts melted and casted into the desired cylindrical and prismatic shapes were good. This foundry had a total cost of around 150 000 XAF. For the project to be done, we used the conceptual tools like horned beast, octopus and the FAST diagrams which allowed us to highlight our need and make the choice of technological solutions in addition to the documentation and YouTube
videos from which we were inspired. Then, several field tests were carried out, which allowed us to have the appropriate clay and facilitate the realization of the furnace refractory core. With this foundry, students and artisans will be formed to aluminium waste remelting and moulding operations.

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