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DEVELOPMENT OF AN INTEGRATED ROTARY SMELTING FURNACE FOR RECYCLING AND RECOVERY OF ALUMINIUM FROM USED ALUMINIUM MATERIALS

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EXECUTIVE SUMMARY

Aluminium occupies about 8% of the Earth's crust. It is the most abundant metal in the world after oxygen and silicon. Its uses are quite widespread, ranging from aircraft design and building construction to automobiles, packaging, and domestic and industrial food processing utensils and equipment. Currently, 70% of aluminium products are recyclable, and improvements in that percentage are ongoing. Refining virgin aluminium has a number of challenges and disadvantages, such as gas emission, extractive cost, higher handling cost, limited possibility, energy cost, and processing cost. The cost of refining virgin aluminium is more than 10 times the cost of recycling aluminium from scrap. Used aluminium products such as pots, cans, utensils, roofing sheets, automobile parts, and others are wasting away within the polytechnic community, Ilaro town, its environs, the state, and all over the nation. Manpower training for the host community and the students on some vital industrial machines to acquire necessary practical knowledge is a challenge for industrial growth and national economic development. Aluminium Smelting Furnace (ASF) has proven to be effective and efficient in recycling and recovery of aluminium from used aluminium materials. The ASF, shredding machine, briquetting machine, magnetic separator, and other equipment and logistic operations will be deployed to achieve the targeted objectives.Testing and quality control of the product will be carried out through various mechanical, metallurgical, and characterization tests. The recycling site will be named Federal Polytechnic Ilaro-Aluminium Recycling Centre (FPI-ARC). The commercialization of the recycling process will preserve the exhaustible raw materials, save energy by 85%, reduce gas emission, reduce mechanical process, create employment, reduce waste at the dumping site, train manpower for the steel industry, provide aluminium ingots for the industries, generate revenue for the government, align with the Sustainable Development Goals (SDGs), ensure raw materials

security and sustain the circular economy for industrial growth and national development. The recycling process is sustainable. Ultimately, an aluminium ingot product will be launched. The total cost of the project is four-three million, two hundred eighty-seven thousand only and the project will be completed in twelve months.

INTRODUCTION

Aluminium is a non-ferrous metal. Aluminium occupies about 8% of the Earth's crust. It is the third most common element in Earth. Aluminium is used in aircraft design, building construction, air conditioning units, refrigerators, domestic and industrial food processing utensil and equipment, and automobiles (among many uses).

Steel technology is the bedrock of and hallmark of any vibrant, strong, and people-oriented economy (Joseph and Anat, 2015). The Industrial Revolution brought advancement in steel technology. The Asian tigers (China, India, Malaysia, North and South Koreans) experience rapid economic development as a result of their steel technology advancement. The development of steel technology enables a nation to become an industrialized nation. Materials that can be recycled are considered to be environmentally friendly. Recycling, recovery, and reusing of materials are the trends of the present-day innovations, which guarantee balance in the ecosystem, save energy, prevent material extinction, and reduce costs and environmental pollution. Unlike some materials, aluminium can be recycled, recovered, and reused up to 60%. Metal scrap recovery is a large industry that processes in the U. S. alone 2.5 million tons of scrap aluminium on a yearly basis (Capuzzi, *et al*., 2017). Rotary furnace is a barrel-shaped furnace that is efficient in aluminium recycling and recovery. It rotates about its axis when performing a metal melting operation (Neikov, *et al.,* 2019). It has a high heat efficiency and easy pressurization while providing heat uniformity and good contact of the recycled material with the reaction gas (Adewuyi, 2020; Neikov *et al.,* 2019). Used aluminium materials and scraps are littered around the community, Ogun State, and the nation, causing environmental challenges (Akintade *et al.,* 2025). These challenges can be solved through recycling using the ASF to sustain the steel industry. This research study will bring growth and development to the steel industry, meet the local aluminium demand, provide lifelong learning and training for the students, and provide consultancy services to the community.

STATEMENT OF THE PROBLEM

Aluminium scraps from cans, utensils, used cooking pots, air conditioning units, refrigerators, automobile, and others are littered in the community as waste and causing environmental challenges. Aluminium materials that are needed for producing machine parts, building construction, air conditioning units, refrigerators, domestic and industrial food processing utensil and equipment, automobile and other uses are not all produced locally. Steel technology needs to be developed as the bedrock of our vibrant and strong economy, hence it is facing a moribund situation.

Raw materials from the earth are exhaustible. It cost 400% higher to produce virgin aluminium than recycled aluminium of the same quality. Virgin aluminium is not sustainable. Mechanical process in production of virgin aluminium is more than recycling process. Alignment with the Sustainable Development Goals (SDGs) is facing a set-back for green technology and eco-friendly environment through extractive process in the mining industry. Employment rate is increasing daily. Revenue generation by the institution and government agencies is reducing with respect to national need and infrastructural development rate. Hence, the need to commercialized the aluminium recycling process to produce aluminium ingot for the small- and large-scale industries and bring an end to these local and national challenges.

OBJECTIVES OF THE STUDY

- Development of an integrated Aluminium Smelting Furnace (ASF) for aluminium recycling
- Installation and operation of the ASF and other machinery and equipment
- Procurement, processing, and pre-treatment of aluminium scrap
- Smelting of scrap and production of aluminium ingot through recycling
- Testing and quality control of the ingot for integrity and quality assurance
- Commercialization of the product through the recycling process
- Create employment and generate revenue for the institution and the government.

LITERATURE REVIEW

A furnace is one of the essential equipment in casting technology. A perfect furnace is a furnace that reduces wastage of materials and reduces the cost of production (Varum *et al.,* 2018). Joseph & Anat (2015) defines a rotary furnace as a heat-treating furnace of circular construction, internally covered with refractory lining, which rotates the charged materials around the axis of the furnace during the melting process, while the charged materials are transported through the furnace along a circular path. A rotary furnace can simply be referred to as an Aluminium Smelting Furnace (ASF). Rotary furnaces are better for smelting scrap and other solid inputs and dominate copper wire refining in primary smelters (Schlesinger *et al.,* 2011). Due to lower stack losses, rotary furnaces are more efficient than reverberatory furnaces and are used primarily to melt scrap containing about 70% aluminium (Olalere *et al.,* 2015). Olalere et al. (2015) affirmed that the operating cost of the rotary furnace will not be high since used engine oil could be used to fire the furnace, and it is relatively available, hence the incessant increase in the price of fossil fuel will not affect the operating and production costs of the furnace. Aluminium recycling is expected to reduce the carbon footprint of the industry to a significant extent in the next ten years, Olalere *et al.* (2015). Aluminium recycling yields the best results of purity level of secondary aluminium when every step, from sorting, shredding of the aluminium scrap to re-melting, is performed with precision.

Comminution is a process of conditioning the scrap sizes and shapes to positively affect the melting rate of the scraps. The advantage of comminution is the possibility of removing foreign materials such as rubber, iron, plastic, magnesium, and others from the aluminium alloy (Capuzzi, *et al.,* 2017). It is typically used in the mining process to separate materials wth respect to their properties, such as high ductility, weight, heterogeneity, sizes, shapes, etc, for high-purity recycled products (Li *et al.,* 2011).

Efficient sorting and shredding are the key to effective aluminium recycling, making the scrap melt-ready in desired shapes and sizes, by applying compressive force, robotic hammering, and shearing force (Li *et al*., 2011). ALTEK (2020) reported that rotary furnaces are more common in Europe than reverberatory furnaces due to their energy efficiency. The melting process involves mainly thermo-hydrodynamic processes in addition to chemical reactions, mass transfer, phase change, surface reactions, porous media flow, free surface flow, combustion, radiative transfer, and fluid-solid interaction mechanism (Varun *et al.,* 2018)

METHODOLOGY

The materials and equipment needed for the Aluminium Smelting Furnace (ASF) will be sourced locally. The construction and operations of the ASF will follow standards for safety, health and environmental regulation. Appropriate materials will be selected. The rotary furnace will be constructed in accordance with the project objectives, design analysis, material selection, and the expected results. The materials of the base frame will be welded together using the electric arc welding process and the designed dimension. The grove of the pulleys and shaft will be milled using a lathe and milling machines. Both the pulleys and the shaft will be mounted on the base frame. The shaft is connected to the reduction gear, while the reduction gear is connected to the electric motor through a gear drive. Thereafter, the steel shells will be carved and rolled to shape. The refractory lining clay of the furnace will be prepared using the ASTM E 11 standard test sieve.Standard test sieve woven wire of normal 500µmopening and DIN ISO 3310-1 will be used to sieve the clay. Fire block will be used to construct the furnace lining with the appropriate standardization. Thereafter, all the other accessory parts will be installed.

The shredding machine will be fabricated in accordance with the project objectives, design analysis, material selection, and the expected results. The frame support will be welded using the electric arc welding process. The angular steel will be welded together to form the framework. The 10 mm thick sheet plate will be cut to size and shape and welded to form the blade cutter housing. The housing will be drilled in two places at the breadth sides of the housing for the shaft to rotate smoothly. The blade cutter will be set on the two shafts and held firmly to the shafts using keyways and keys. Two spur gears will be fixed to the two shafts which extend to outside the blade cutter housing. The two spur gears are made to mesh and rotate one another. The shafts in turn rotate the blade cutter to shred and shear the aluminium scraps when the electric motor is turn on. The hopper is fixed on the upper part of the housing to feed the scraps and protect the operator from the danger of crushing hands. The shredding machine is needed to reduce the size of a large volume of aluminiu scrap for efficient and fast smelting and to save energy.

The magnetic separator will be used to remove ferrous materials from the aluminium scrap before charging it into the furnace. The gas treatment plant will be deployed to reduce gas emissions and convey leftover gas emissions to the outside environment. After completion, the rotary furnace will be tested to smelt the scrap. The product will be subjected to metallurgical, mechanical, and characterization test to know the quality and integrity level. The performance evaluation entire process and the workflow will be carried out.

Figure 1 shows the flowchart of the aluminium smelting process for the recycling and recovery of aluminium.

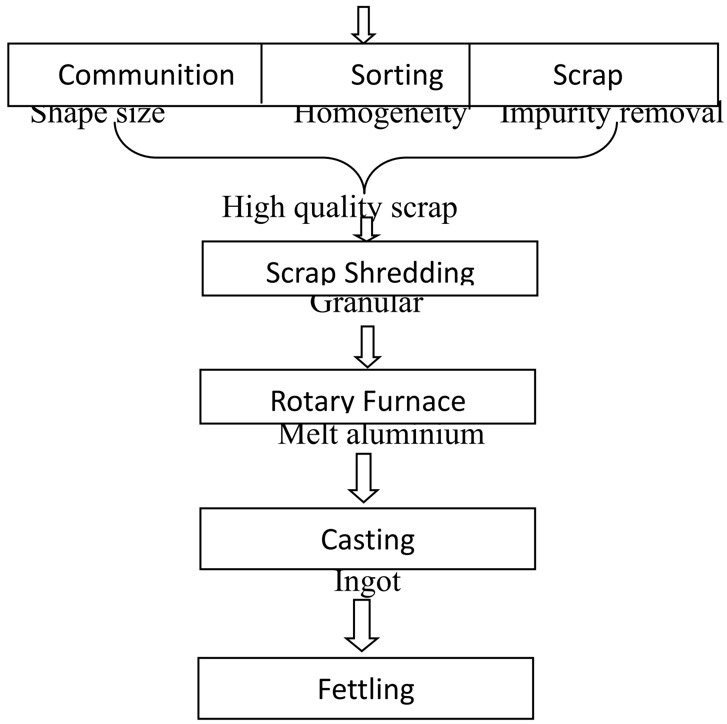

Fig. 1: Flowchart of the aluminium smelting process for recycling and recovering of aluminium

EXPECTED RESULTS

The commercialization is expected to produce a complete aluminium recycling process, which comprises an integrated rotary furnace, a magnetic separator, a shredding machine, a briquetting machine, a flue gas treatment plant, other equipment, and accessories for an efficient recycling process. Establishment of the Federal Polytechnic Ilaro-Aluminium Recycling Centre (FPI-ARC) through a sustainable aluminium recycling process. Commercialization of the aluminium recycling process. Create employment for the community. Train manpower for the steel industry.

Produce aluminium ingot for the industries and generate revenue for the institution and the government. Ensure raw materials security and sustain the circular economy for industrial growth and national development. Ultimately, launch an Aluminium ingot product.

WORK PLAN/PROJECT TIME

S/N	Activity	Outcome	Duration (month)
1	Pre-research study and design of machine	Design of the project	2
2	Sourcing for materials and parts	Purchase of materials	2
3	Construction and processing	Completion of the machine construction	4
4	Experimentation and testing,	Completion of the machine testing and performance evaluation	2
5	Data collection and analysis	Results collation	1
6	Writing of project report	Completion of project report and journal publication	1
	Total		12 months

GANTT CHART

MONTH												
Task name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Activity 1												
Activity 2												
Activity 3												
Activity 4												
Activity 5												
Activity 6												

BUDGET

1. **Rotary Furnace**

SN	ITEMS	PROCEDURE	FUNCTION	QTY	COST (NAIRA)
1	Electric gear motor (5 hp)	Purchasing	Prime mover	1	400,000.00
2	Shaft (hardened steel)	Fabrication	Power transmission	2	540,000.00
3	Coupling	Purchasing	Connection	1	180,000.00
4	Grooved pulley	Fabrication	Power transmission	4	380,000.00
5	Furnace frame	Purchasing	Support	4	300,000.00
6	Base frame (I-Beam steel)	Purchasing	Support	4	390,000.00
7	Riding ring steel	Purchasing	Transmission	2	600,000.00
8	Refractory lining materials	Construction	Heat resistance	1	440,000.00
9	Gas firing system	Purchasing	Firing furnace	1	390,000.00
10	Furnace shell (Steel)	Fabrication	Heating chamber	1	380,000.00

11	Industrial fan blower	Purchasing	Air blower	1	235,000.00
12	Plummer block	Purchasing	Shaft support	4	440.000.00
13	Furnace foundation (Concrete)	Construction	Furnace support	1	540,000.00
14	Liquified Natural Gas (LNG) cylinder	Purchasing	Gas storage	1	350,000.00
15	Packets of welding electrodes	Purchasing	Welding	5	75,000.00
16	Cutting and grinding disc	Purchasing	Finishing	6	42,000.00
17	Furnace oil tank	Purchasing	Oil storage	1	380,000.00
18	Furnace opening mechanism	Fabrication	Opening furnace		180,000.00
19	Temperature measuring system	Purchasing	Temperature detector	2	340,000.00
20	Mould	Construction	Ingot casting	10	580,000.00
	Subtotal				7,162,000.00

2. **Aluminium Scrap Shredding Machine**

S/N	ITEMS	PROCEDURE	FUNCTIONS	QTY	COST (NAIRA)
1	Shaft (Hexagonal cross-section)	Fabrication	Cutter rotation	2	480,000.00
2	Electric gear motor (3 hp)	Purchasing	Prime mover	1	380,000.00
3	3-Teeth blade cutter	Fabrication	Scrap cutter	24	580,000.00
4	Steel ring	Fabrication	Cutter guide	26	420,000.00
5	Hopper	Fabrication	Scrap receiver	1	80,000.00
6	Duct passage and tray	Fabrication	Scrap passage	1	85,000.00
7	Machine frame	Fabrication	Sheet support	1	380,000.00
8	Spur gear (hardened steel)	Fabrication	Power Transmission	2	380,000.00
9	Guiding plates	Fabrication	Guide plates	26	464,000.00
10	Shredding casing	Fabrication	Houses cutters	1	150,000.00
11	Set of bearing	Purchasing	Support shaft	4	200,000.00
12	Set of long-threaded fastners	Purchasing	Cutter support	24	96,000.00

13	Set of nuts	Purchasing	Cutter support	24	24,000.00
14	Frame guide	Fabrication	Case guide	4	96,000.00
15	Packet of welding electrodes	Purchasing	Welding	1	15,000.00
16	Cutting and grinding disc	Purchasing	Finishing	4	28,000.00
	Subtotal				3,858,000.00

3. **Aluminium Scrap Briquetting Machine**

S/N	ITEMS	PROCEDURE	FUNCTION	QTY	COST (NAIRA)
1	Hydraulic boom (20 tons)	Purchasing	Compress scrap	1	420,000.00
2	Hydraulic control unit	Purchasing	Control system	1	250,000.00
3	Hydraulic electric motor	Purchasing	Pump fluid	1	380,000.00
4	Machine frame	Fabrication	Machine support	1	380,000.00
5	Hopper and machine plate	Fabrication	Machine body	1	280,000.00

6	Scrap delivery platform	Fabrication	Scrap receiver	1	40,000.00
7	Packet of welding electrodes	Purchasing	Welding	1	15,000.00
8	Fluid power hose	Purchasing	Fluid transmission	4	300,000.00
9	Hydraulic fluid tank	Purchasing	Fluid storage	1	340,000.00
10	Cutting and grinding disc	Purchasing	Finishing	4	28,000.00
	Subtotal				2,433,000.00

4. **Flue Gas Treatment Plant**

S/N	ITEMS	PROCEDURE	FUNCTION	QTY	COST (NAIRA)
1	Industrial extractor fan	Purchasing	Heat extracting	2	460,000.00
2	Flue gas duct	Fabrication	Gas passage	1	380,000.00
3	Chimney duct	Fabrication	Gas exit	1	240,000.00
4	Metal sealants and	Purchasing	Sealing openings	1	100,000.00

	adhesives				
5	Packets of Aluminium fasteners	Purchasing	Sheet fastening	4	60,000.00
6	Chimney concrete base	Construction	Chimney support	1	200,000.00
7	Baghouse filters	Purchasing	Reduce particulate emission	3	270,000.00
8	Cutting and grinding disc	Purchasing	Finishing	2	14,000.00
9	Hand riveting machine	Purchasing	Fastening sheet	1	65,000.00
	Subtotal				1,789,000.00

5. **Magnetic Separator**

S/N	**ITEMS**	**PROCEDURE**	**FUNCTION**	**QTY**	**COST (NAIRA)**
1	Magnetic separator	Purchasing	Separate Iron from Aluminium	1	3,860,000.00
2	Receiving container	Fabrication	Materials receptor	2	340,000.00

3	Tools and accessories	Purchasing	Maintenance	1	220,000.00
	Subtotal				4,420,000.00

6. **Other Items and Transportation**

S/N	ITEMS	PROCEDURE	FUNCTION	QTY	COST (NAIRA)
1	Land	Acquired from institution	Site for centre	1	Not applicatble
2	Building	Construction	Houses centre	1	15,200,000.00
3	Sand bucket (Metal)	Purchasing	Extinguish fire	4	60,000.00
4	Fire extinguisher	Purchasing	Extinguish fire	3	540,000.00
5	Testing and quality control	Purchasing	Product integrity	10	680,000.00
6	Electric heater	Purchasing	Firing furnace	5	500,000.00
7	Pre-treatment of scrap	Purchasing	Preparation of scrap	5	360,000.00
8	Licensing and permits	NESREA, FMEnv. and local govt.	Permission to operate	1	1,350,000.00
9	Maintenance	Operation	Equipment	-	440,000.00

			maintenance		
10	Transportation	-	Transportation	-	980,000.00
11	Report documentation	-	Documentation	3	300,000.00
	Subtotal				20,410,000.00

7. **Consumables**

S/N	**ITEMS**	**PROCEDURE**	**FUNCTION**	**QTY**	**COST (NAIRA)**
1	Liquefied Natural Gas	Purchasing	Firing furnace	50 kg	100,000.00
2	Aluminium scrap	Purchasing	Raw material	100 kg	100,000.00
3	Fluxes	Purchasing	Impurity removal	75 kg	280,000.00
4	Utilities	Purchasing	Operations	-	375,000.00
	Subtotal				855,000.00

8. **Research Personnel**

S/N	NAME	DESIGNATION/ QUALIFICATION	ROLE IN RESEARCH	AFFILIATION	HONORARIUM (NAIRA)
1	Joseph O.O.	Senior Lecturer, HND, PGD, M Eng., PhD (Mech.), MNSE, COREN	Principal Investigator	The Federal Polytechnic, Ilaro, Ogun State	500,000.00
2	Joseph, O. O.	Associate Professor, B. Eng., M. Eng., (Met. and Mat.), PhD (Mech.) MNSE, MNMS, COREN	Co-Investigator	Covenant University, Ota, Ogun State	450,000.00
3	Akintade J.O.	Chief Lecturer, B Eng., M Eng. (Mech) MNSE, COREN	Co-Investigator	The Federal Polytechnic, Ilaro, Ogun State	450,000.00
		Sub-total			1,400,000.00

9. **Labour**

S/N	STATUS	NUMBER	QUALIFICATIONS	ROLE IN CENTRE	WAGES (NAIRA)
1	Procurement Officer	1	ND (Purchasing and Supply Technology)	Scrap procurement	100,000.00
2	Furnace Operator	2	ND (Metallurgical	Smelting	400,0000.00

			Engineering)	Operation	
3	Utility Officer/Supervisor	2	ND (Mechanical Engineering)	Utility procurement	220,000.00
4	Sorting Officer	2	ND (Metallurgical Engineering)	Scrap sorting and preparation	200,000.00
5	Cleaner	1	SSCE	Centre cleaning	40,000.00
	Subtotal				960,000.00

10. **Budget Summary**

S/N	ITEMS/DESCRIPTION	TOTAL COST (NAIRA)
1	Rotary Furnace	7,162,000.00
2	Aluminium Scrap Shredding Machine	3,858,000.00
3	Aluminium Scrap Briquetting Machine	2,433,000.00
4	Flue Gas Treatment Plant	1,789,000.00
5	Magnetic Separator	4,420,000.00
6	Other Items and Transportation	20,410,000.00
7	Consumables	855,000.00
8	Research Personnel	1,400,000.00
9	Labour	960,000.00
	Grand Total	43,287,000.00

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