# LEAD-ACID BATTERY CONSTRUCTION USING LOCALLY SOURCED RECYCLED MATERIALS

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Abstract - The incessant export of disused lead-acid batteries across the shores of Africa at very low prices and the subsequent importation of products made from these disused batteries at exorbitant costs is of great concern to us, and other well-meaning Africans. In a bid to mitigate this, we have used locally sourced parts of disused lead-acid batteries to construct a battery that was able to crank up a vehicle. Using the principle of electrolysis, new lead dioxide plates which served as the battery's positive plates were produced from only the lead plates extracted from disused starter batteries. The battery parts were assembled in a plastic casing and dilute sulfuric acid (the electrolyte) was added to build the battery unit. The battery was tested and the result showed an open circuit voltage of 12.81 V, a capacity of 1,137 mAh, and a self-discharge rate of 31% per week. The battery was successfully used to start a vehicle.

Keywords: lead-acid battery, disused batteries, lead dioxide plates, electrolysis, sulfuric acid

# **1. INTRODUCTION**

The Lead-Acid battery was the first rechargeable battery. It was invented in 1859 by Gaston Plante, a French physicist [1]. A scientist named Camille Alphonse Faure improved the Lead-acid battery, thus increasing the battery's capacity significantly [2, 3]. Irrespective of the advancement, it has a relatively low energy density of about 35 - 40 Wh/Kg compared to other secondary batteries [4, 5]. Lead, Pb, serves as the anode plate, and lead dioxide, PbO2, serves as the cathode plate; both immersed in a dilute sulphuric acid electrolyte [6]. Each electrode plate is made up of a grid alloy which is daubed with sponge-like lead or lead dioxide materials [7]. The positive grid is a mesh-like alloy of lead, calcium, tin, and silver; while the negative grid is a mesh-like alloy of lead and calcium [8]. These grids are known as current collectors, which are responsible for carrying electrons into and out of the cell. Each electrochemical cell produces 2.1V, typically. This implies that a 12V Lead-Acid battery comprises six cells that deliver a voltage of 12.6V typically [9]. The plates are prevented from shortcircuiting with the aid of some porous polyethylene materials called separators, which also help in gas evolution [10].

The earliest lead-acid batteries used only liquid sulphuric acid electrolyte and hence, are called flooded lead-acid batteries. However, through technological advancement, the valve-regulated Lead-Acid batteries were produced, which uses electrolytes that are either in gel form (GEL batteries) or absorbed in a glass fiber mat separator (AGM batteries).

The flat-plate flooded lead-acid batteries are mostly used in cranking of vehicles' engines but the tubular type is used for energy storage in renewable energy power plants. The GEL and AGM valve-regulated lead-acid batteries are mostly employed in the energy bank of photovoltaic power plants and other renewable energy power plants because they are capable of withstanding deep discharge cycles of up to 80% depth of discharge, hence they are called deep cycle batteries. These batteries support deep cycling because their plates are thick [11]. The flooded lead-acid batteries used in cranking engines are called automotive starter lead-acid batteries or starting, lighting, and ignition (SLI) batteries. They are made of flat thin plates, with the same low energy density (35 to 40 Wh/kg), of lead-acid batteries but a higher power density; hence, they are capable of releasing large current bursts for a short period to crank engines. The thin nature of its plates grants the battery's reacting materials a larger surface area, thus increasing the reaction rate and allowing the release of large current bursts necessary for cranking [12]. Current exits or enters the battery when connected to an external load, or an external DC source (charger), respectively. This initiates a reversible redox reaction within each cell, which is observed as sulphation/desulphation of the plates, cum fluctuations in the electrolyte's specific gravity [13].

 $Pb \Leftrightarrow Pb^{2+} + 2e^{-}$ Anode: (1a)

$$Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4 \tag{1b}$$

Cathode:  $PbO_2 + 4H^+ + 2e^- \Leftrightarrow Pb^{2+} + 2H_2O$ (2a) (2b)

 $Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4$ The overall reaction is:

$$Pb + PbO_2 + 2H_2SO_4 \Leftrightarrow PbSO_4 + 2H_2O \tag{3}$$

Sulphation has been the most popular issue of Lead-Acid batteries. This is a consequence of poor charging activity after each discharge cycle. It leaves some amount of PbSO<sub>4</sub> on the plates, which when allowed to accumulate for a long time, turns almost irreversible; thus depleting the active materials of the cells, and thereby damaging it [14, 15]. It has been reported that a sulphated lead-acid battery can be desulphated and thus rejuvenated by recharging the battery using a high-frequency pulse desulphator [16].

However, the major issue of Lead-Acid batteries which depletes it of its positive plates is known as positive grid corrosion. It involves the gradual corrosion of the battery's positive plates when water from the electrolyte oxidizes large portions of the positive grid into PbO<sub>2</sub> during the discharge/charge cycle; the corroded part of the grid sheds off, thus making the battery devoid of active positive cells [17, 8, 18]. The negative lead plates do not corrode but may reduce in size due to shedding off of lead particles after several charge/discharge cycles [6]. Batteries that have been largely attacked by positive grid corrosion, lack the potential to crank engines.

By extracting the intact lead plates from disused starter batteries, and oxidizing them in water via electrolysis, the lead plates can be recycled into lead dioxide plates [19]. The major aim of this work is to carry out a reproduction/replacement of the corroded positive plates in a disused starter battery through some local processes, using only the extracts from a second disused starter battery.

### 2. MATERIALS AND METHODS

The materials used include Lead plates, extracted from two disused batteries, half of which are oxidized to produce positive lead dioxide plates; Porous polyethene materials which were also extracted from the disused batteries to be used as separators; Distilled water for electrolysis; Tetraoxosulphate VI acid of 1.275 specific gravity used as the electrolyte and also to complete the electrolysis process; Lead solder used to make good electrical and mechanical joints between the six compartments of the battery; Graphite electrode used to generate the necessary heat energy for melting the lead solder; and Transparent Perspex material used to construct the battery casing's lid.

The lead and lead dioxide plates were extracted from the disused batteries after cutting them open. However, the lead plates were found intact and in order, while the lead dioxide plates were found shattered due to positive grid corrosion. These can be seen in figures 1 and 2.



Fig. 1 - The intact negative lead plates



Fig. 2 - A corroded positive lead oxide plate

The extracted lead plates were arranged to obtain six 9-plate stacks of four assumed positive plates, and five assumed negative plates. The assumed positive and negative plates were alternately arranged, separated by separators, and immersed in a pool of distilled water. This implies that only lead plates served as both electrolytic anodes and cathodes; the voltage of this battery arrangement was measured to be 0 V before it was connected to a 20.40 V DC charger. These are shown in Figures 3 and 4.



Fig. 3 - The 9-plate stacks of assumed positive and negative plates of the battery



Fig. 4 - The new battery arrangement as it is being filled with distilled water

The positive terminal of the 20.40 V charger was connected to the electrolytic anode (which is the cathode of the battery), and the negative terminal of the charger to the electrolytic cathode (which is the anode of the battery). With this, current flowed through the waterelectrolyte and the electrolysis of water started. Oxygen is generated at the electrolytic anode while hydrogen is generated at the electrolytic cathode. Lead being a reactive metal, undergoes oxidation with the liberated oxygen gas, thus, lead dioxide was formed at the electrolytic anode. This oxidation reaction was aided by an increment in the temperature of the plates because such metals as Zn, Fe, Sn, Pb, and Cu form their metallic oxide when heated in the air [13]. The reaction equations are given in equations 4 to 7.

Electrolytic anode (electrochemical cathode) reaction:  

$$20H^{-}_{(aq)} \Rightarrow O_{2(g)} + H_{2(g)} + 2e^{-} \qquad (4)$$

$$Pb_{(s)} + O_{2(g)} \Rightarrow PbO_{2(s)} \qquad (5)$$

$$2H^{+}_{(aq)} + 2e^{-} \Rightarrow H_{2(g)}$$

$$Pb_{(s)} + H_{2(q)} \Rightarrow Pb_{(s)} + H_{2(q)}$$
(6)
(7)

The charging process lasted for about three days, after which the battery's voltage was measured to be 7V. Then, the distilled water-electrolyte was discarded from the cells (as it has been depleted of ions), and was replaced with a dilute solution of sulphuric acid of 1.275 relative density; and the charging process continued for another two days after which the voltage was measured to be 12 V. The battery casing's lid was then put in place and the battery was sealed. The battery was further charged for 12 hours and the open-circuit voltage stepped up to 12.81 V. A picture of the produced battery is shown in Figure 5.



Fig. 5 - A picture of the produced battery

A discharge test was carried out to determine the capacity of the battery. A standard battery discharger and analyzer, SkyRC BD200 interfaced with a computer, was used for the discharge test. The battery was discharged at a constant –current rate of 5.0 A, and to a discharge-end voltage of 11.5 V. The discharge results comprising voltage, current, power, and capacity against time plotted by the discharger software, were saved. Figure 6 shows the battery discharger and analyzer software's screenshot depicting the discharge settings and plots.



Fig. 6 - The battery discharger software's screenshot showing the settings and plots

A second test was done to determine the battery's self-discharge rate. The battery was recharged and the open-circuit voltage was measured and recorded. The voltage was then measured every 12 hours for 4 days and the result was recorded.

Finally, a car starting test was carried out on the battery, and the picture of the battery as it was being used to start a vehicle is given in Figure 7.



Fig. 7 - The battery being used to crank up a vehicle's engine

### **3. RESULTS AND DISCUSSION**

After the electrolysis process that lasted for five days, the voltage of the battery stepped up to 12 V, with each cell giving a voltage of 2 V. This simply implies that the lead plates connected to the positive terminal of the charger have largely undergone oxidation, forming lead dioxide as a result of electrolysis in water and dilute sulphuric acid. Further charging gave rise to a voltage of 12.81V; this was the maximum open-circuit voltage recorded. The relative density of the dilute acid in each cell was measured to be 1.30. From the discharge test, the battery capacity was determined as 1,137 mAh (or 4,093 As). The discharge voltage and power were plotted against time as shown in Figure 8. This shows that the battery's capacity is very much lower than the 75 Ah capacity of the standard lead-acid batteries of similar size. The low capacity means that the active materials in the battery are low in quantity. This is likely a result of the inefficiency of the oxidation process used to convert the lead-plate positive electrodes to lead dioxide plates.



Fig. 8 - The battery's discharge voltage and power against time

Despite the measured low capacity, the battery was able to crank up a vehicle. In a bid to find out why this was possible, we came up with the following: Crankingup a vehicle consumes a current of about 300 A to 800 A over a period of less than 2 seconds (which means a capacity of 600As to 1600As), and this must lie between 0 to 20% of the battery's capacity [8]. Our battery's capacity is 4,093 As, and 20% of it is 818.64 As which lies within the required 600 As to 1,600 As range. This, therefore, shows why our battery was able to start a vehicle.

From the self-discharge test results, the battery's measured open-circuit voltages were plotted against time to obtain the self-discharge curve shown in Figure 9.



Fig. 9 - The battery's self-discharge curve

The self-discharge rate of the battery was determined from the trend line of the curve as 0.023 V/h. This implies a self-discharge rate of 31% per week which is very high compared to the 4 - 6% per month selfdischarge rate for new lead-acid starter batteries [20]. This is believed to be due to an increased electrolyte/active material ratio, which is responsible for an increase in the surface area of the reactants, thus increasing the rate of the battery's open-circuit internal reactions.

#### 4. CONCLUSION AND RECOMMENDATION

A new lead-acid battery with enough capacity to crank up a vehicle's engine can be produced using only the lead plates extracted from two disused batteries and with half of the lead-plates set configured to serve as positive plates and converted to lead dioxide via electrolysis in deionized water and dilute sulphuric acid.

The starter battery that we produced via this method showed a capacity of 1,137 mAh and a self-discharge rate of 31% per week but was able to crank up a vehicle's engine.

The low capacity and high self-discharge rate could be as a result of low active materials caused by inefficient positive plates lead oxidation process and lower thickness of the plates compared to those of brand new batteries as a result of the shedding off of chunks of crystals from the electrodes after several charge/discharge cycles in the initial batteries they served

Further research should be done on ways of improving the quality of the plates to obtain a battery of better characteristics.

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#### DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.