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Battery Services International
Battery Specialists

Morphology of Battery Failures

A BSI Instructive Flyer

This document provides a detailed view of the morphology of lead acid batteries as they decay from strong state of charge and good state of health to poor performance and failure. It is a narrative based mostly on ten years of field experience dealing with lead acid batteries of all kinds and make. We share it in the hope to invite dialogue on the prevailing issues that causes lead acid battery's good health to decay as it is used in any application thought off today.

Morphology of Battery Failures

There are several factors that contribute to battery failures. These factors have a compounding unfavorable effect in any battery's state of charge (SOC) and its state of health (SOH) at any given point of the battery's life span. This means that the accumulated energy in a battery is incrementally reducing its total capacity available to do work as it ages. This decline in capacity is associated with a progressive change in the nature of the plates active materials of spongy lead (Pb), spongy dioxide lead (PbO_2), and sulfuric acid (H_2SO_4). The two spongy leads active materials start out with abundant porosity and less hard crystallinity texture to later change to a lack of porosity and a much more hard crystal presence in the lead paste mass found on the plates. This suggests that as the battery ages the lead pastes in both negative and positive grid plates loses porosity, hardens, and expands before dead.

The hard crystals referred above are described on most electrochemical journals dealing with lead acid batteries as hardening of the *positive active material* (PAM which is same as PbO_2) and hardening of the *negative active material* (NAM which is same as Pb paste). Commonly worldwide and through the Internet people associate this "hardening" of the paste as *sulfation buildup*. However, *sulfation buildup* is best described as *hardening of the lead sulfate mass* ($PbSO_4$) that is found on its discharged state on both negative and positive plates. The lead sulfate is the precipitation product of the chemical reaction of $Pb + PbO_2 + H_2SO_4$ (*spongy lead + spongy dioxide lead + sulfuric acid*) to produce energy when a load is applied to the battery. The energy produce is proportional to the amount of hydrated soft lead sulfate mass available to react when exposed to electric load of charging or discharging. Below is a microscopic view of healthy lead paste (new battery) as it changes to hard sulfation buildup over the cycle life span of lead acid batteries.

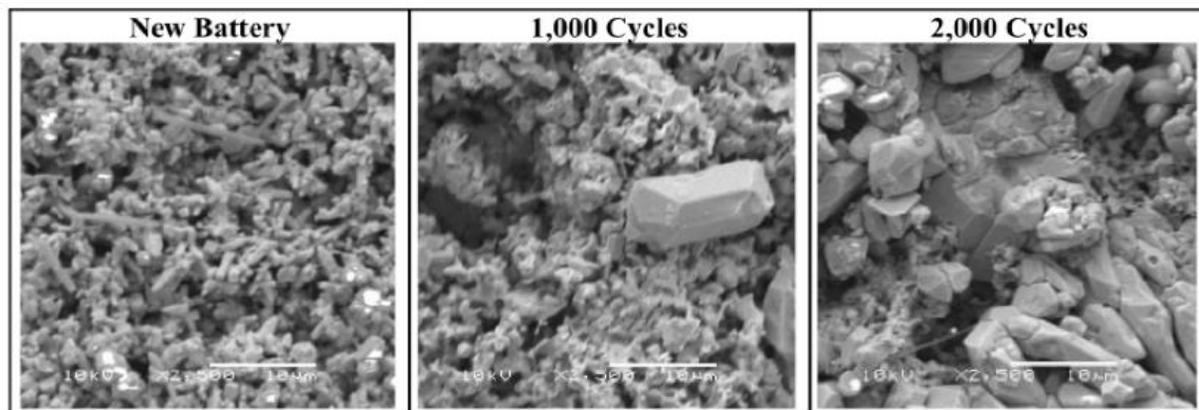
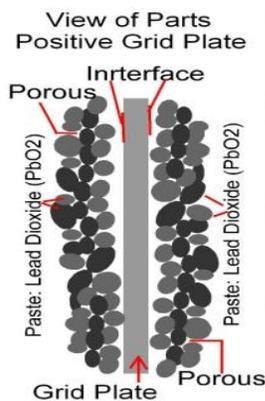


Image taken from the Internet.

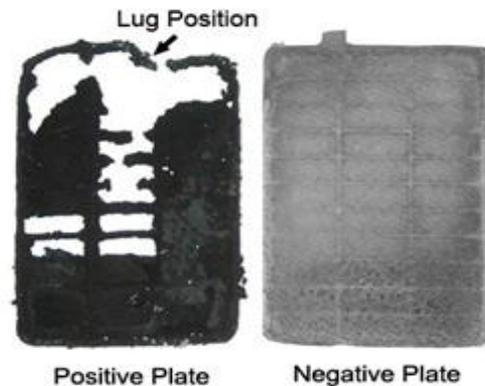
The offset of sulfation buildup causes for a reduction in reactivity in the NAM and PAM pastes, and in sulfuric acid. Thus, this passivation rendered the battery no longer able to meet its original expected design life and capacity. Sulfation buildup is acknowledged on many scientific papers as the leading cause of lead acid battery passivation causes. Together with corrosion layer growth it is assumed to be a natural evolution on all types of lead acid batteries. However, it is also known that sulfation buildup is a catalyst that propels other ills in the battery such as higher resistance to accept a charge, short runtime, increase in exothermic events, accelerates gassing, and decay of the PAM. It can reduce healthy NAM and PAM mass area to react with sulfuric acid, causes bulging of the casing and shedding, contributes for burnt and shorted cell plates, and lack of internal compression. Overall, hardening of the lead sulfate paste, commonly known as sulfation buildup, it is not a desirable occurrence as it is detrimental for all lead acid battery state of charge and state of health.

Furthermore, it is expected that conventional cycling of batteries can invoke the growth of soft spongy dioxide lead particles (PbO_2 or PAM) at the surface of the positive lead plate grids. This spongy positive lead paste growth can be of the type PbO_2 or PbO and usually grows in the positive plate in an area commonly known in battery electrochemical science as the *interface zone*. This area it is generally known as the area where the PAM and the NAM pastes make contact with the grid plate surface. The growth of excess PbO_2 is also referred to as *corrosion layer evolution* in scholarly papers. Due to distortion in exothermal occurrence the lead dioxide (PbO_2) can decay as lead monoxide (PbO) and can grow enough to cover all the interface lead plate surface area on both sides of the positive plates. This evolution once takes place inhibits good contact between lead paste and plate grids surface. If there is no contact between lead pastes and the lead grid plate surface then the conductive pathway to transport electrons *in* or *out* of the battery is inhibited. This can cause for the battery to have poor performance and eventually will fail.

View of Positive Plate Affected with Corrosion & Negative with Sulfation.



Cell pack with corrosion & sulfation in both plates.



Source for this image is <http://batteryuniversity.com>.

This unhealthy corrosive layer is comprised mostly of lead monoxide (PbO) and together with sulfation buildup it is responsible for the increased in internal resistance (Ohm) in all lead acid batteries. Dehydration also causes for all kinds of battery blocs to have high resistance, low conductivity, and weak plate integrity. Of course, the resistance values (Ohmic) caused by sulfation buildup is always below that found on any corrosion layer, any dehydrated battery, in any battery with buckled plates, and in any battery with shorted or burnt cells. It should be known that chronic corrosion layer is associated with dissolution of the lead plate material that is also acknowledged as aiding in plate buckling, and short circuiting plates or burning cell plates as well lead paste shedding. Further decline in battery capacity due to reduced available re-active surface area both at the plate surface and lead paste mass is accompanied with reduced battery acid strength. This in turn results in lowered battery voltage and capacity output accelerating shedding of active lead material in both negative and positive plate.

Continued conventional charging at high voltages is associated with excessive gassing, increased crystallization of paste, increased operating temperature, increased corrosion layer evolution, longer charging cycles, higher electric consumption of the chargers, and lesser runtime or service capacity. All of these symptoms can result in physical damage to the battery caused by *plate buckling*. Overall the battery will exhibit physical and chemical distortion due to crystal growth both at the interface (corrosion layer or PbO) and hardening of PAM and NAM lead pastes which yield heat damage due to internal high resistance to accept charge. The growth of both lead paste as it hardens and the corrosion layer evolution are associated with the bulging of the battery plastic casing. It also has being linked to dendrites or tiny crystals that perforate the plate separators causing accelerated auto-self discharge and, when it is pervasive enough, shorted cells.

Another catastrophic evolution that can take place is shorted cell plates. The shorted cells can evolve at two fronts. One way is as the lead paste hardens as crystals these hard crystals find their way across the thin polymer separator between positive and negative plates. Once crystals of one plate cross to the other side then they begin to make contact with the specimens of the other plate which have opposite polarity. This contact causes a soft short circuit first, and later develops as a stronger short circuit that drains battery potencies that can be measured as lower *open circuit voltage*, lower *specific gravity*, lower *voltage under load*, and lower *amp-hour capacity*. At the beginning, this contact between hard lead paste crystals is visible by increased parasitic electric drainage accelerating auto-self discharge in the battery. As the population of lead paste specimens making contact with each other increases a shorted cell takes place, depriving the battery from retaining energy and delivering it to meet expected service performance.

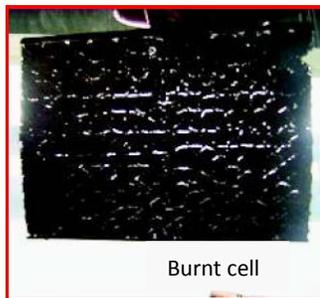


The other way shorted cells happens it is by expansion and shedding of both NAM and PAM lead paste active materials. A short circuit of this manner takes place as the lead on both plates expands and sheds to the bottom of the battery container where there is allotted space in the *sediment trap* area. As the lead paste materials piles up it can reach the bottom area of the plates that are resting on top of the sediment trap liners. This evolution is understood to create a short circuit effect that significantly drops open circuit voltage, voltage under load, specific gravity of the battery electrolyte, and amp-hour capacity. Some argue that this phenomenon of *shorted cells* should have a better designation because it is similar to an *elevated self discharge* than a short circuit. However, in BSI we feel that naming it is not the issue for us as that is an academic matter. Our concerns are with field practice and *know how* that matches real life regarding lead acid batteries morphology and behavior.

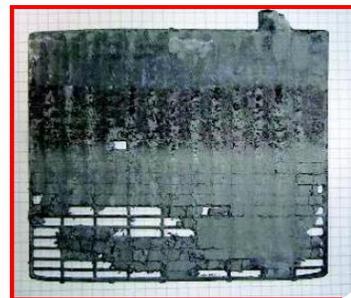
On most automotive cranking batteries the shedding is manageable because the lead plates are thin and the battery does not go through as deep a discharge as deep cycle ones. On the other hand, if shedding is present in a deep-cycle battery then this should be a concern because the discharging of the battery accelerates due to this shorting event in between plates of opposing polarities. Typically, deep cycle batteries that are shorted will exhibit low runtime performance. Below is a view of shedding and burnt on lead plates.



Shedding of active mass caused by heavy cycling - little active material left.



Burnt cell



Shedding can be caused by low cycling and poor charging too.

High voltage spikes are caused by increased gassing. This may contribute to premature battery failure, especially in sealed non-serviceable flooded type of batteries and in VRLA,

AGM, and Gel batteries too. Gassing means that the battery will lose water in the electrolyte because a percent of the oxygen and hydrogen gases that can recombine to make water leaks out of the battery. As the battery dries out the capacity and voltages drops, specific gravity drops while resistance to accept a charge increases. The battery will heat up faster to higher temperature breaking down more water. The water loss causes the sulfuric acid to get stronger fueling for mossing to develop as a systemic event that causes damage to both NAM and Pam pastes and also to the grid plate structure by means of corrosion and sulfation. The water steam will also carry sulfuric acid into the air propagating corrosion to the wiring leading to the battery as well as the battery mounting hardware.

Excessive gassing it also can cause that thermal runaway occurs. Thermal runaway is associated with battery ruptures, accelerated gassing or even explosions. As the battery dries out also the hardening of the lead sulfate accelerates leaving less surface plate area for electricity generation. Excessive gassing then is a derivative of high voltage charging causing also acceleration of corrosion layer of amorphous monoxide lead (PbO) and propels that healthy PbO₂ lose an oxygen molecule becoming monoxide lead too. As we discussed earlier, monoxide lead will increase resistance to charger input leading to discharge plates and damages such as buckling and shedding. On the other hand, some discount batteries may exhibit excessive gassing simply due to inferior materials and substandard battery designs. Nevertheless higher voltage levels will "gas" the battery and boil off electrolyte, again shortening battery life. As you can see, the morphology of lead acid battery failure is complex and interconnected. In summary, all of the causes to poor battery performance yield the same systemic failure event: passivation (dead) of the three main active materials in the battery: NAM, PAM, and sulfuric acid. Our battery solution process and products solves all these problems listed and described in this document.

Below please find a graphical view of the expected normal chemical reaction in a battery when all its active materials are participating fully in the reaction with a good health state:

