

# Advances in VRLA battery technology for telecommunications

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Received 22 September 2006; received in revised form 3 November 2006; accepted 7 November 2006

Available online 11 December 2006

## Abstract

Wide scale use of the newly emergent VRLA (valve-regulated lead-acid) battery in telecommunication applications and the subsequent problems encountered early in their deployment history spurred intense efforts to improve the design as a continuous endeavor. After implementing improvements to battery placement and containment design to prevent the sudden onset of thermal runaway, the focus of the development work has been on cell internals. These include improved grid and strap alloys, superior AGM (absorbent glass mat) separator that retains compression in the cell, use of beneficial additives to the active materials and the need to avoid contaminants that promote detrimental side reactions. These improvements are now resulting in a vastly superior VRLA experience in the telecommunication applications. To further improve the reliability demanded by today's communication and internet environment VRLA battery installations should include continuous cell/module and system monitoring similar to that incorporated in competing advanced battery systems under development.

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*Keywords:* VRLA; Telecommunication; Grid alloys; AGM separators; Reliability

## 1. Introduction

The last two decades have seen tremendous growth in the use of VRLA (valve-regulated lead-acid) batteries in telecommunication and other backup power needs. VRLA batteries made with AGM (absorbent glass mat) separators as the means of electrolyte immobilization have become the preferred product for standby “float” applications. Quite apart from the various well-documented thermal runaway incidents, there has been a large deficit in the service life experienced in the field versus what was expected. In part this is due to the common user not always correctly interpreting the expected service life, which may have been derived from various claims made by the manufacturers. These latter claims discuss the “Design Life,” which are for a set of ideal conditions and must be suitably modified to reflect the environmental conditions and the installation modes. In the early stages of deployment, many sites had exposure to high temperature ambient conditions. Some had ill-advised placement of the battery in close proximity to heat generating electronics. These led to a few well-publicized catastrophic incidents. Reacting to

these, a flurry of development activity was undertaken by the battery manufacturers to improve the product. The very first was on the need to contain the danger of thermal runaway. This was largely achieved through appropriate containment design, improvements to the cell (or module) placement, improved ventilation and use of current limiters that responded to temperature extremes. However, it was recognized that there is need for more. This is illustrated by the shortfall experienced even in deployments in ‘controlled environments’ comparable to that of ‘Vented’ (also called ‘Flooded’) cells. Field data [1] for 558 VRLA battery systems are presented in Fig. 1(a), together with that of 772 vented battery systems, shown in Fig. 1(b). Both types were installations exposed to similar environmental conditions. As can be seen,

- A. The VRLA batteries shown in Fig. 1(a) exhibit premature failure in 3–4 years. The data is predominantly for the so-called 20-year designs, mixed with some mono-blocks (5–10 year designs).
- B. The vented batteries of Fig. 1(b) generally meet or exceed the 20-year life expectation, although a few failures are seen, indicating that there is room for improvement there too.

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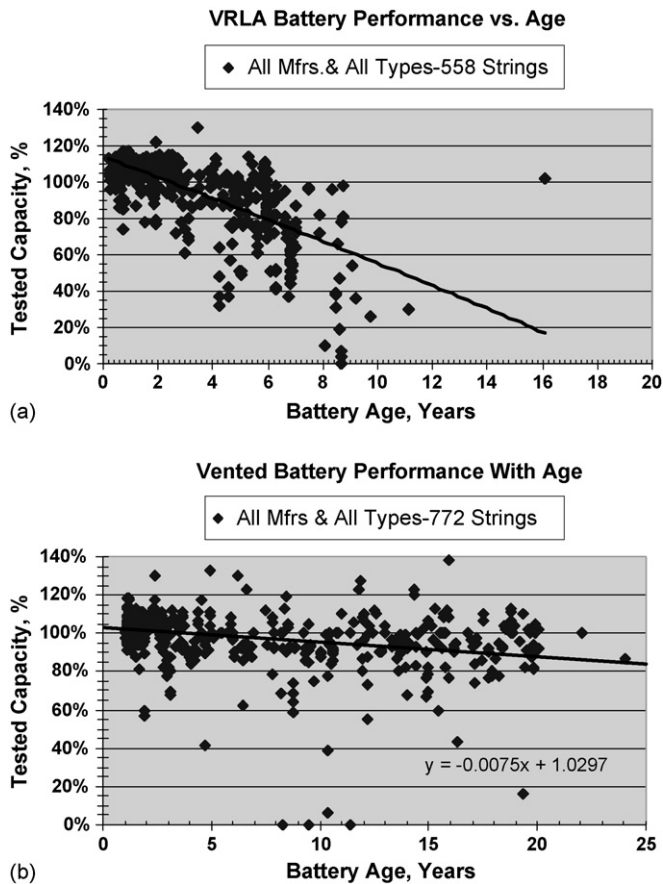


Fig. 1. (a) VRLA battery performance vs. age and (b) vented battery performance vs. age.

Root cause analysis of failed battery systems determined the need to direct the development efforts towards improving the various internal cell components. A primary failure mode was found to be the degradation of the positive plate from grid corrosion. That created the need to develop more corrosion resistant grid alloys. Failure to retain compression of the electrode elements due to degradation of the AGM separator was also found to be critical. Use of improved grades of AGM separators and attention to cell compression in design and manufacturing has minimized variability and thus provided a more uniform product. Additives have been developed that improve the charge acceptance behavior on float while reducing the float current and thus maintain a healthier battery system. A large contribution to the control of float current has also come from changing the active material balance between the positive and the negative plates in the new designs. Catalysts have been suggested as a means to further lower the water loss, the float current and therefore further improve the battery life. The author has published [2] a detailed report on the impact of internal catalysts in VRLA and since not much has changed, that aspect will not be repeated here. This review discusses the protocol used in designing the early generation of VRLA that may have caused this shortfall. It goes on to analyze in some detail some of the newer developments that have resulted in improved products.

## 2. Development history of vented lead-acid cell and the early VRLA designs

The history of the vented lead-acid cell spans more than 130 years, during which it has seen numerous incremental developments that needed verification and validation. The service life of a newly installed battery providing backup power is expected to span several decades. Given that time span, it has been customary to utilize accelerated tests to initially validate a design, which is then introduced in the field.

### 2.1. Design validation methodology for the vented cell

In the development of newer flat plate type vented cells it has been customary to use test methods where elevated temperature is the means of acceleration. Cells are held on ‘float’ in hot rooms maintained at various temperatures, removed from time to time and tested electrically until failure occurs. The temperature acceleration protocol was pioneered by Willihnganz [3] and has been adapted by the IEEE and BCI as established practice. More refined data for commercial telecommunication cells of the flat plate type utilizing lead–calcium grid alloys was later presented by Brecht et al. [4] at the 1988 and 1989 International Telecommunications Energy Conferences (Intelec). The work established that the continued electrical performance of vented cells are largely determined by the longevity of the positive grid, which is subject to continuous corrosion and growth. It also established that the rate of growth is significantly impacted by the polarization at the positive plate. It was determined that the end of life for large telecommunication cells that use lead–calcium (Pb–Ca) family of grid alloys can be linked to a predetermined percentage of growth of the positive plate. The growth of Pb–Ca alloy grids occurs exponentially, i.e., it accelerates with time. The time to failure for the cell was correlated to the test temperature. A service life at room temperature was predicted utilizing Arrhenius principles. The Arrhenius plot for two types of commercial telecommunication cells with Pb–0.03% Ca alloy grids of 0.26 and 0.31 inch thickness respectively is shown in Fig. 2. The data shows life to 3.5% plate growth, although the cells will continue to perform to ~5% growth and hence almost 20% more life is still available. The data was generated [5] by placing groups of cells in a number of hot rooms that are separately maintained in the range of 49–71 °C. The positive plate potential was held between 70 and 80 mV and cell performance as well as plate growth were measured from time to time, similar to the protocol detailed in Ref. [4]. The extrapolation to 25 °C predicts a service life in excess of 20 years. Field data presented earlier in Fig. 1(b) verifies the prediction and thus validates the methodology.

The significant impact of positive plate polarization on grid growth (and life) is shown in Fig. 3, normalized to the life at 100 mV as the base. It shows that while the best ‘Relative Life’ can be expected at about 30–80 mV of positive polarization, the worst outcome will be at higher polarizations. Some of the premature failures in the field have been linked to such operation, which also promotes increased shedding of active material that leads to failure from shorting out between plates.

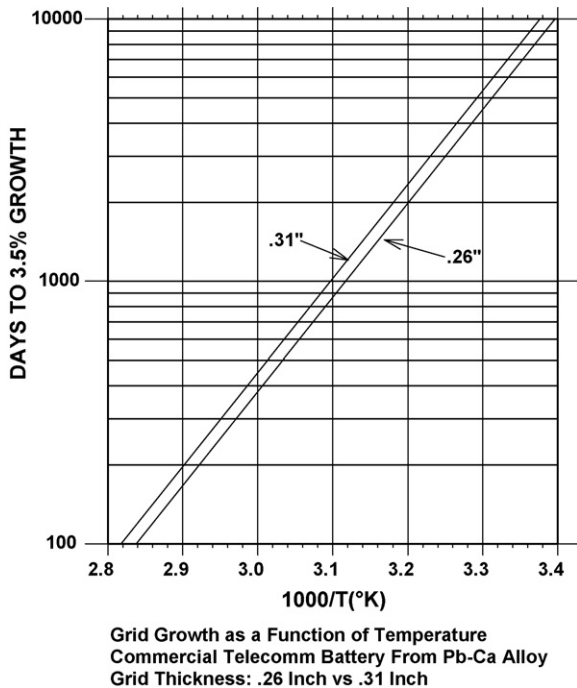


Fig. 2. Arrhenius plot for life expectancy of vented cells at multiple temperatures.

## 2.2. Early VRLA cell development

Successful VRLA cells were initially developed in a cylindrical configuration and in small sizes to compete with portable nickel–cadmium cells. The use of AGM mat as separator in these cells allowed easier transfer of the oxygen gas (evolved at the positive plate during charge) to the negative plate, thus making a high level of oxygen recombination possible. While such recombination suppressed loss of water due to electrolysis during charge, it could not totally eliminate hydrogen loss from self-discharge at the negative plate. Hence it was necessary to use a vent valve that opened as needed to release head-space gasses and prevent excessive pressure build up that could damage the cell. The chemical and electrochemical reactions involved during charge and overcharge have been discussed in detail and summarized in a tabular form in an earlier publication [2], identifying the source of this hydrogen gas to be primarily due to

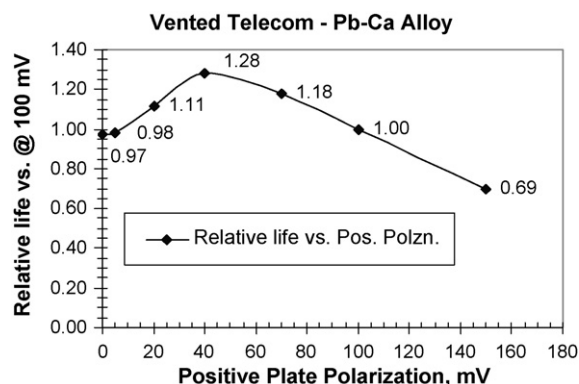


Fig. 3. Impact of positive plate polarization on relative life of vented cells.

reactions occurring at the negative plate. It shows that, unlike in vented cells, this loss of hydrogen gas results in water loss in the VRLA cell that is not replenished. Clearly, it is necessary to use grid lead free from alloying elements that reduce the inherently high hydrogen over-potential of pure lead as well as to minimize any contaminant that has the same impact.

Scaling up of small cylindrical cells to very large sizes comparable in electrical capacity to large vented cells was not easy and some design changes had to be made. The pressure relief vent had to typically operate at a modestly low level such that the plastic containment vessels and the seals would not be damaged. To enable this and not bring down the expected service life attributable to water loss and dry-out, the internal cell designs had to accommodate a high level of oxygen recombination—achieved initially by over-sizing the negative compared to the positive. In addition, the need to handle large size plates during manufacturing required that the grid alloys have a reasonable amount of tensile strength. That required a judicious selection of the grid alloy. Once designed, it was necessary to verify and subsequently validate the service life of the product.

Early development of large size prismatic VRLA cells followed a path parallel to that of vented cells for design verification, but Pb–Ca was not used as the positive grid alloy. Instead, while one manufacturer used a lead alloy with very low antimony content together with a little cadmium, most others utilized alloys from the lead–calcium–tin (Pb–Ca–Sn) family. The main impetus for this choice is to retain a grid alloy that has higher over-voltage for hydrogen evolution. The latter is expected to facilitate oxygen recombination and thus minimize water loss and resultant failure from dry out. There was another major difference—the specific gravity (s.g.) of the electrolyte was upped sharply (from 1.215 for vented cells to 1.300 for VRLA) to make up for the reduced volume available. The alloy of choice approximated Pb–0.06Ca–0.6Sn together with a small quantity of Al (used for Ca control). This alloy has a successful history in the SLI environment. Addition of tin to Pb–Ca alloys is known to reduce corrosion and provide resistance from developing passivity at the plate-active material interface when operating at higher acid gravity; hence the choice of this alloy in early VRLA cells.

As reported in Ref. [5], the higher the acid gravity, the higher the rate of corrosion and growth. Change to 1.300 s.g. from 1.215 s.g. reduces the float life of vented cells that use binary Pb–Ca alloys by about 30%. However, the ternary alloys with tin have a lower corrosion rate and withstand higher acid concentrations somewhat better. A comparison of the ‘Relative Life’ expected at various positive potentials is shown in Fig. 4, computed to ~4% grid growth. It compares the expected life of VRLA (operating with 1.300 s.g. acid) with that of vented cells operating at 1.215 s.g. acid, based on positive plate corrosion and growth. Such data favored the view that a comparable service life was expected for VRLA cells in float operation since grid corrosion was expected to be the dominant failure mode in telecommunication applications. Laboratory tests verified that oxygen recombination was nearly 100% efficient on float (i.e., on trickle charge) and hence dry out from water electrolysis was ruled out as a possible failure mode in this application. Unfortunately, failures occurred in

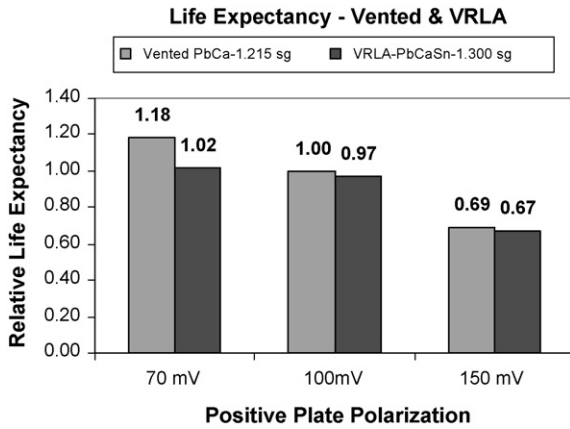


Fig. 4. Relative life comparison for positive grids used in VRLA and vented cells.

actual use much sooner than projected from the laboratory tests, prompting a reexamination of all these basic assumptions.

### 3. VRLA improvement measures

The widely experienced shortfall in the VRLA performance focused attention on the need to improve their stability and reliability. It led to examining every component in the products that failed prematurely to find the root cause for failure. As mentioned in Section 1, incidences of failure due to improper design of cabinets and battery placement that led to thermal runaway could be sorted out and remedied by appropriate action. Those do not merit further discussion in this review. However, Fig. 1(a) in Section 1 shows that the problem is wide spread and extended beyond thermal issues. It was found that in standby use (i.e., on continuous float or trickle charge), the root causes prominently included those of: (a) positive grid corrosion, many times coupled with dry-out from water loss associated with grid corrosion, and (b) degradation of the AGM separator that resulted in its inability to maintain compression imparted initially during cell manufacture (and the consequent degradation of contact and increased ohmic resistance between the plates and the separator). The improvements achieved to address these two critical issues will be discussed first, followed by the other important work involving reduction of float current and additives.

#### 3.1. Improved positive grid alloy

The positive grid is the component that most influences the life of a lead-acid cell, be it the conventional vented lead-acid cells or the VRLA cells, and hence deserves the most attention. Discussion in Section 2 has shown how grid corrosion leads to growth, which in turn results in gradual loss of contact of the active material with the grid and degradation in electrical performance. In vented cells a growth of up to about 5% can be tolerated before failure occurs. Failure analysis of VRLA cells determined that their tolerance to growth is much lower. Additionally, grid corrosion consumes water that cannot be replenished and leads to dry-out, which is a critical additional failure mode for VRLA. A major reason for picking low-gassing

antimony-free alloys for VRLA cells for float use was to minimize dry out. However, the “Conventional” Pb–Ca–Sn alloys with 0.06–0.07% Ca and 0.6–0.7% Sn, used in early generation VRLA, were found to degrade from corrosion much sooner than expected. In part this was due to the higher effective polarization at the positive (resulting in a much higher corrosion rate) in ‘recombinant’ cells with a highly depolarized negative. Thus, vented cells on float have a positive polarization of around 70 mV while that in VRLA cells (with depolarized negative) are at about 120 mV. This difference alone results in a penalty in grid life of ~25%.

The main culprit appears to be the high calcium content in the ‘Conventional’ alloys used, which were picked to provide additional strength. Published data [6] would suggest that an addition of tin in excess of ~0.5% to Pb–Ca would control the corrosion rate and allow the use of a calcium level at ~0.06%, which would provide significantly increased strength. The latter would provide resistance to growth as well as improved handling strength during manufacturing. Fig. 5(a and b) summarize the information in graphical form that makes it easy to visualize this conclusion.

Unfortunately, this expectation, based on short term corrosion tests, failed to recognize the exponential nature of growth in long term exposure. Alloying with tin by itself could not counter the higher level of calcium in the alloys. The culprit appears to be the ultra-high corrosion potential of calcium when compared to most other elements found in the alloy, see Fig. 6. Calcium forms the compound  $Pb_3Ca$  that is present at the grain

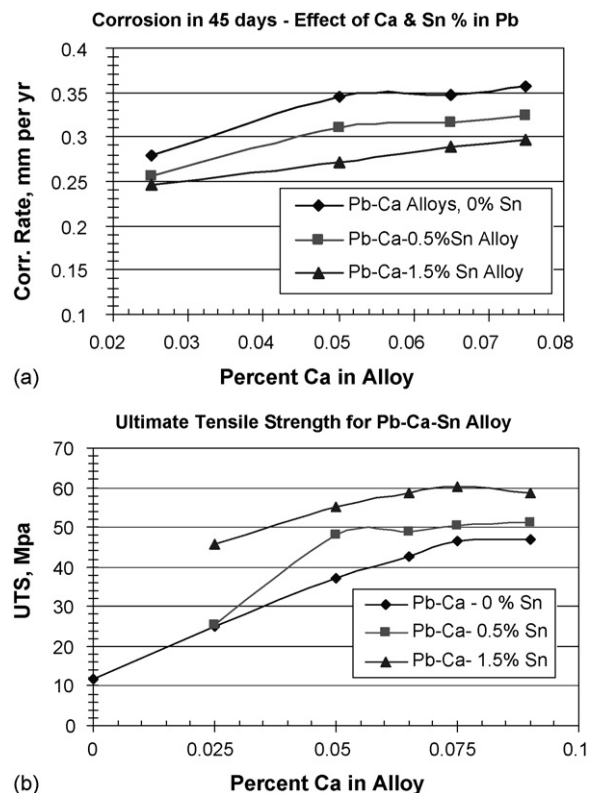


Fig. 5. (a) Effect of Ca/Sn content on corrosion rate and (b) effect of Ca/Sn content on ultimate tensile strength.



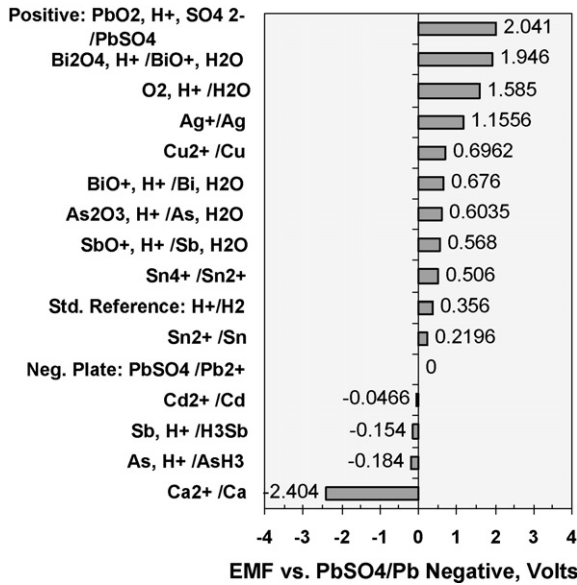


Fig. 6. Standard EMF of common additives and contaminants vs. lead negative plate.

boundaries and corrodes preferentially. Addition of tin, which is more electro-positive, provides a moderating influence even as it impacts the grain structure. It progressively replaces Pb in this Pb<sub>3</sub>Ca compound and an intermediate phase (Pb<sub>x</sub>Sn<sub>(1-x)</sub>)<sub>3</sub>Ca is formed. More tin (beyond the stoichiometric ratio) will eventually completely replace Pb and Sn<sub>3</sub>Ca is formed predominantly. Prengaman [7] has summarized and discussed the large number of published literature on this subject in a recent review; he also addresses the metallurgy inherent to the family of Pb–Ca–Sn alloys.

Newer alloys have been developed that typically contain lower calcium and higher tin contents when compared to these early alloys and are much more corrosion resistant. Table 1 summarizes the composition of some of the alloys in use, together with the ‘Conventional’ alloy. It shows at least two alloys that have differing amounts of silver. In Ref. [7] Prengaman has discussed the beneficial effects of silver as an additional alloying element, which results in increased tensile strength that helps control grid growth at very high temperatures.

3.1.1. Experimental method used in grid alloy tests

Small 102 mm<sup>2</sup>, 3.56 mm thick ‘10-year design’ grids made with these various alloys were tested for corrosion and growth in a flooded environment. Multiple samples were held in 1.290

Table 1  
Grid alloys for VRLA batteries—tested for corrosion and growth

Alloy tested	Nominal composition
Pure lead	Primary lead
Pb–low Ca	Pb–0.03 Ca
Conv. Pb–Ca–Sn	Pb–0.07 Ca–0.65 Sn <sup>+</sup> Al
Low Ca/high Sn	Pb–0.045 Ca–0.90 Sn <sup>+</sup> Al
High Sn–low Ag	Pb–0.045 Ca–1.0 Sn <sup>+</sup> Al <sup>+</sup> 0.013Ag
Low Sn–high Ag	Pb–0.045 Ca–0.65 Sn <sup>+</sup> Al <sup>+</sup> 0.03Ag

Exposed to 1.290 sp.gr. H<sub>2</sub>SO<sub>4</sub> at 55 °C, 125 mV positive polarization.

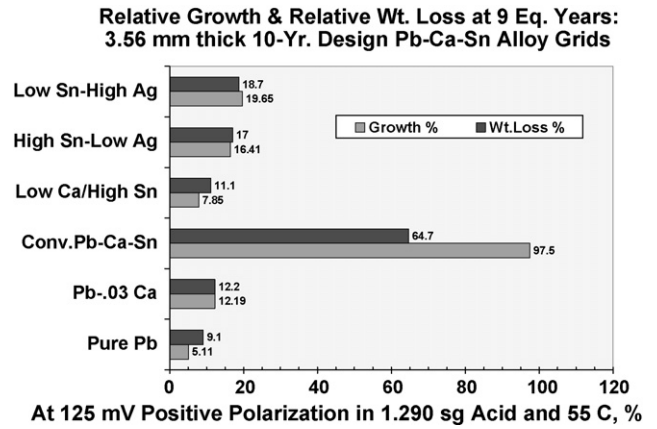


Fig. 7. Relative corrosion and growth of grid alloys for VRLA batteries.

s.g. sulfuric acid at 55 °C and with a polarization set at 125 mV. A few samples were removed from time to time and the weight losses as well as horizontal growth were measured. The author [8] had presented a preliminary report on this at the Intelec 2004 Conference.

3.1.2. Results—grid alloy tests

Relative data for corrosion and grid growth of some of the common low-calcium high-tin alloys are compared in Fig. 7 after ~330 days (nine equivalent years). The ‘Conventional Alloy’ with much higher calcium is used as the basis for comparison. The figure captures the relative data for two low-calcium alloys that have some silver as the additional alloy additive (see Table 1). The data for the binary lead–calcium alloys used in flooded lead-acid cells is also included for comparative purpose.

One can clearly see that grid growth does not always proceed in sync with that of corrosion as defined by weight loss. The reason for this is linked to grain structure and the mode of corrosive attack. Substantial improvement for the low-calcium alloy is apparent, both in corrosion and growth, which will directly relate to improved battery life. Onoda et al. [9] claim much improved results by substantially increasing the tin content, while holding the calcium content at the conventional level. The reported benefit is, however, not as good as that of the low calcium alloys. Clearly, the calcium content in the alloy and how it relates to the tin content are the main controlling factors that influence the rate of corrosion and growth. The metallurgical structures for these alloys is such that penetrating corrosion at the grain boundaries is minimized, with vastly reduced growth of the positive grids, thus prolonging the retention of intimate contact between the active material and the grid.

3.2. AGM separator

The dominant VRLA products in standby usage are those that use the AGM technology. That is the reason for limiting this discussion only to AGM technology. Electrolyte immobilization with AGM separator that continues to maintain firm contact between the plates within is a key requirement for long life VRLA products. Good plate to electrolyte contact is achieved by applying a steady compressive force to the separator mat.

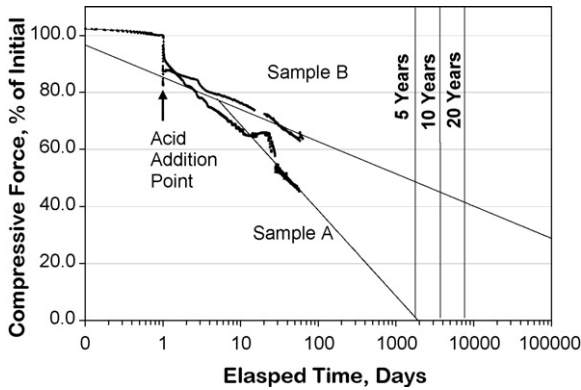


Fig. 8. Compression resistance of AGM separator.

However, the mat has been identified as a weak link, since it fails to retain compression as the cells age, which affects battery performance.

Building long life VRLA batteries is linked to the ability to identify and use grades of AGM separator that maintain compressive force as the batteries age. In Ref. [10] the author disclosed a test method that can be used to assess the stability of any grade of AGM under compressive load. The method consists of placing a predetermined number of layers of the AGM separator, contained in a polyethylene bag, within a fixed gap formed by two adjustable metal plates so as to simulate the battery design. AGM separator grades on test, representing assorted density and surface area (indicative of different blends that have differing fiber grades and contents), are thus subjected to compressive loads that simulate conditions in the battery. The actual force is measured with load cells attached to one of the plates and decay of this force versus time is tracked. After checking the initial dry response the mat is wetted with a measured quantity of sulfuric acid electrolyte reflecting battery conditions. This relaxes the resistive force provided by the AGM. Fig. 8 illustrates the response to such conditions by two different grades of AGM mats as a function of time on a logarithmic scale. From a design perspective, adequate compressive force must be retained over the expected service life of the VRLA cells. It is quite apparent that one of these mats, marked as ‘Sample A,’ is degrading (in terms of retention of compressive force) quite fast and will have inferior performance with respect to plate contact as time progresses. The other mat, designated as ‘Sample B’ in this figure, is projected to retain resistance to the compressive forces even as the time period exceeds the design goal for the product.

Use of this test method, although time consuming, allows one to select an appropriate grade of AGM separator for building superior VRLA cells. The inherent problem with AGM is illustrated by the response profile—since intimate contact between the plates and the separator is compromised with time, any shrinkage of the mat from dry-out will further compromise battery performance.

### 3.2.1. Improvements to the separator

One suggested improvement to AGM is to blend polymeric fiber, typically polyester micro-fiber. Unfortunately, in small percentages these blends do not appear to improve on the abil-

ity to retain wet compressive force. They do provide improved mechanical strength that allows the use of thinner sections during cell assembly when the design demands it.

Gel is the other common method for immobilizing the free electrolyte and a method to develop a hybrid gel technology [10] that combines gel with AGM has been proposed. In some standby applications VRLA batteries with the conventional gelled electrolyte have been promoted as the superior technology. A problem with this technology has been that of shrinkage of gel away from the active mass [11] in the plates as it undergoes loss of water due to its inferior gas recombination capability, which results in faster dry-out—a common failure mode for VRLA cells. Presence of gel does however provide an additional electrolyte reserve and superior thermal properties for the battery. Therefore, while the AGM-based technology has been the preferred approach for immobilizing the battery electrolyte (because of their inherently superior oxygen recombination efficiency), combining it with gel to formulate the “hybrid gel” has been suggested as a means of improving [10] the VRLA products, particularly in cycling applications. Superior thermal properties have been demonstrated that extends the long-term reliability in cycle service and in adverse environmental conditions. Gel provides an electrolyte reservoir while AGM ensures retention of plate contact for efficient ion transfer. However, for the long term float applications where charging conditions are not as severe, this benefit is yet to be demonstrated.

High surface area powdered silica-loaded AGM mat has been developed as an alternative to the impregnation method described, for which various patents exist. In another development, published through ALABC (Advanced Lead Acid Battery Consortium) sponsored research, use of membrane type materials that restrict oxygen transfer and thus improve charge acceptance of the negative have been found beneficial in cyclic use modes.

### 3.3. Additives and positive and negative active materials balance

It was discovered during failure analysis that a sizeable number of failures could be ascribed to performance loss due to significant self discharge at the negative plate. That refocused examination of the prevailing thought that a highly depolarized negative is necessary to maximize oxygen recombination and therefore control water loss. When oxygen recombination occurs through formation of an intermediate compound ( $\text{PbO}/\text{PbSO}_4$ ) that requires recharge to regenerate the sponge lead, a highly depolarized negative may not make that happen as efficiently. In vented cells the negative remains healthy only when it is slightly polarized, and the same may be required even in VRLA cells. A direct reduction of the molecular oxygen can occur on the sponge lead surface, and self-discharge is suppressed at the same time. It was realized that the amount of oxygen gas evolved on float is not high and hence it is easily transported and recombined in the VRLA cell, even with a polarized negative. Reducing the float current in turn reduces the magnitude of oxygen gas evolved that needs to recombine. In addition, a depolarized negative (with a

lower Tafel slope) contributes towards much higher float current and hence is more susceptible to thermal runaway when the ambient temperature is high. Therefore it is desirable instead to design for a polarized negative plate that will substantially reduce the float current.

To reiterate, (a) *Original hypothesis*: depolarized and over-size negative facilitates recombination, controls gassing and therefore prevent dry-out, versus (b) *Newer thought*: polarized negative keeps the VRLA healthy, lowers float current and therefore reduces grid corrosion, and the product is less sensitive to thermal runaway.

The required changes have been achieved by the use of “additives” in active materials and through adjusting the active material balance to favor the positive. Increased amount of derivative lignin and carbon additives to the negative plate have changed their polarization behavior more akin to that of vented cells.

Various other additives have been proposed to increase the stability of the active materials. Carbon in various forms and other conducting additives that stabilize the active material have been claimed to allow improved charge acceptance. Substantially increasing the carbon additive to the negative active material results in reduced active surface area and thereby increases the over-voltage at the negative, which reduces the float current.

Changing the active material balance through higher positive to negative active material ratio is another approach to reduce the ratio of negative and thus effectively increase the current density. This action automatically decreases the current density at the positive plate and increases that at the negative plate. In yet another approach Onoda has suggested [9] the use of higher density negative active material to achieve similar results.

Various manufacturers have used all or some of these changes. Typical example of cell and plate polarization behavior in a newer mono-block design is compared versus a conventional product in Fig. 9(a and b). The newer product has shown improved stability in the field. The differences between the negative plate responses to increasing current are apparent between the two. The newer models have negative plates that behave very much like vented cells. However, the gassing and dry-out behavior of these newer products has been found to be no worse than that of the early generation VRLA products. In Fig. 10 the current voltage behavior of a large size newer design single-cell VRLA is compared to that of equivalent products from two other conventional early generation models. As seen before for mono-blocks, a substantial reduction in float current is observed, which can be ascribed to an earlier onset of the “Tafel break” at the negative plate. The newer designs have a float current that is almost an order of magnitude lower than the conventional models—the latter have a more depolarized negative. This helps the newer design cells to withstand increased ambient temperatures without as much propensity for thermal runaway.

3.4. Effect of contaminants

Float current and negative self-discharge can be substantially affected by the presence of contaminants. It is necessary

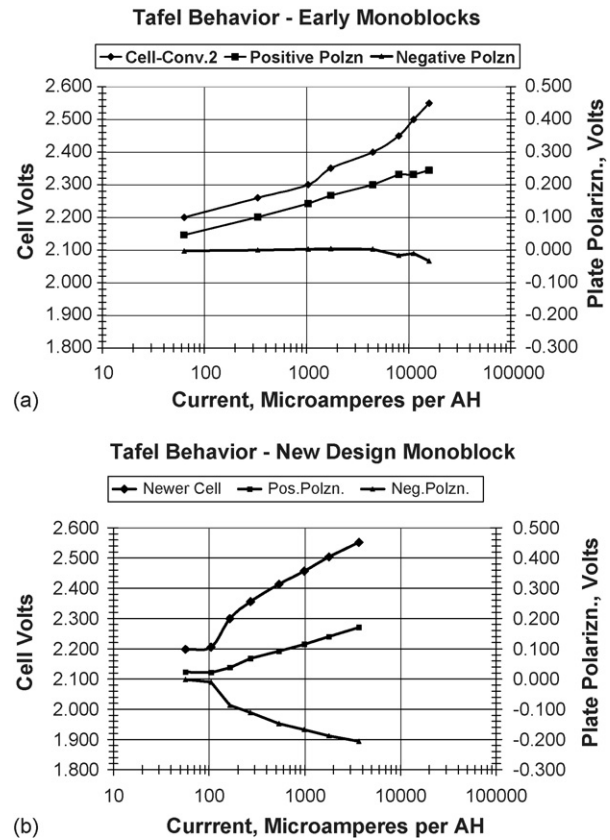


Fig. 9. (a) Cell and plate Tafel plot for a conventional mono-block and (b) cell and plate Tafel plot for a newer mono-block.

for VRLA systems to utilize pure components all around. This includes the lead oxides used in the active material and the electrolyte filled in the cells to activate them. Contaminants that affect the positive include those that would promote grid corrosion, or those that lower the oxygen over-voltage. Contaminants for the negative are those that lower the hydrogen over-voltage, or affect the charge acceptance reaction. Typically, primary lead (as distinct from secondary or recycled lead) is used preferentially for the oxide used in the manufacture of VRLA cells. If secondary lead is used, it has to be of acceptable purity and must be closely monitored for the presence of small amounts

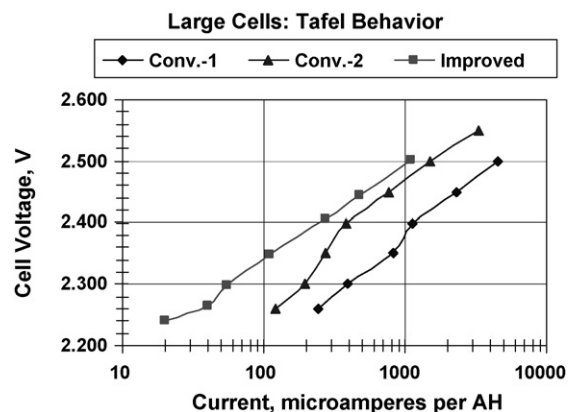


Fig. 10. Current–voltage behavior of large VRLA cells—conventional and newer design.



of those elements that are known to reduce the hydrogen and oxygen over-voltage. Similar is the case with the sulfuric acid electrolyte. In most of the manufacturing operations use of de-ionized water may be necessary for controlling the presence of such contaminants. Most transition metals are known contaminants that are harmful to VRLA cells.

#### 4. Discussion

Many of the changes discussed in Section 3 for improving the VRLA experience have already been put in effect by various manufacturers within the past several years. The question comes as to how the benefit of these changes can be validated by demonstrating increased reliability and service life. As seen in Fig. 1(a), it takes several years before the performance shortfall can be experienced in the field. A presentation from C&D at Battcon-2005 demonstrated the improvement in life in accelerated life test [12] at elevated temperatures for their new large-size VRLA cells—the latter incorporates a low-Ca alloy in combination with a few other changes. EnerSys Inc. tracks the warranty experience of their large VRLA products and has seen a substantial reduction in the failure rate between the 1990s and the 2000s. This data, obtained through private communication [13], is illustrated in Fig. 11.

Most other major manufacturers have made similar claims. These are encouraging developments. The lessons learned from almost two decades of such development activity by many professionals have been influential in making available a current generation of VRLA products that have achieved a considerable measure of enhancement. Today the life expectancy in float applications is substantially higher than those early days of VRLA, but the first impression still lingers. Competitive ‘Advance Battery Systems’ routinely use the very limited life experienced by the early VRLA generations in their analysis, but improved VRLA of the current generation provides substantially more value to the customer.

##### 4.1. System consideration

An aspect not discussed above, but remains of paramount importance is that of overall system consideration and proper design of the installation. The much discussed dangers of thermal runaway that destroys the battery in a very short time has been largely managed by paying attention to the system and hav-

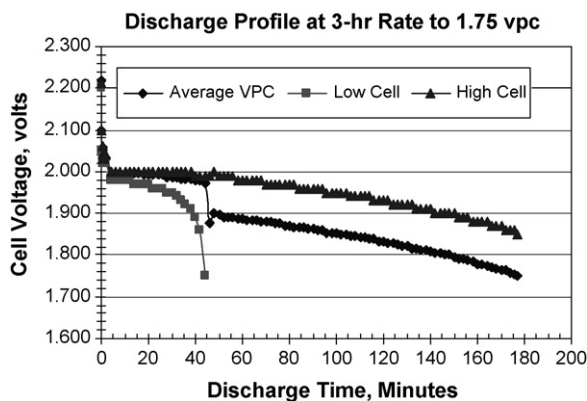


Fig. 12. Performance profile at a VRLA installation after 2.5 years.

ing automated thermal management in place at the installation. A simple method utilizes a temperature monitor that senses the battery temperature and provides feedback to the charger for control of the charge current.

While the effective life of the new generation VRLA battery is substantially higher than suggested by the early experience, the warranty comparison and field experience suggests that it is still prone to unexpected failure. An example of this can be seen from the data generated by TPI Inc., USA [1], at two large sites that employ an array of high quality new generation VRLA batteries. At one of these sites that houses eight batteries, one cell in a battery string was found defective during a performance test conducted after about 2.5 years. This computes to a failure rate at the cell level of only about 0.5% at that site. Diagnostic tests that included the ‘ohmic value’ test did not detect a problem prior to start of the electrical test. The discharge profile, shown in Fig. 12, clearly shows presence of the bad cell; fortunately it did not compromise the protection time to a significant extent. Since individual cells were being monitored, it was easy to identify the defective cell. Adequate time will be available in such cases for proactive action of replacing the defective cell and provide full protection. This is where the need for system monitoring will pay dividends and provide much superior reliability.

#### 5. Conclusion

Much improvement has been made on the matter of VRLA battery reliability since the early field problems surfaced. Newer grid alloys and other improvements in current use demonstrate superior performance in accelerated tests, but validation of longer battery life in the field will take time. Research funded by the ALABC, the results of which have been summarized in a book [14], has identified beneficial additives and contaminant control that should also further the cause.

#### Acknowledgements

Voluminous field data for vented and VRLA batteries was provided by Bill Cantor of TPI Inc., Exton, PA, which greatly contributed to the author’s perspective on their comparative

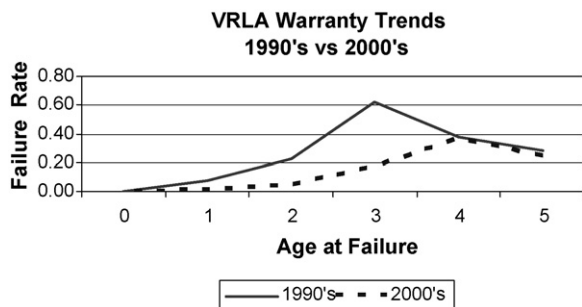


Fig. 11. Failure rate of VRLA—experience of EnerSys Inc.



performance—only a small fraction of the data is included in this review. John Gagge of EnerSys Inc. provided the warranty information for their large size VRLA products, which is gratefully acknowledged. C&D Technologies allowed the use of hot room data for their newer product in comparison with some of their other large VRLA cells, which helps to illustrate the advances made. The author wishes to acknowledge a long and productive association with C&D Technologies. Much of this knowledge was acquired during his tenure there, spent on developing and improving vented and VRLA cells for the industrial market place.

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