THE STUDY OF INTERNAL OHMIC TESTING IN DETECTING INITIAL LEAD-ACID BATTERY DEFECTS

Michael Nispel
Dir. of Product Management
and Technical Support

John Kim
Senior Product Manager

C&D Technologies, Inc.
Blue Bell, PA 19422

INTRODUCTION

The use of instruments to directly or indirectly measure the internal resistance of the valve-regulated lead-acid (VRLA) cell has dramatically increased in recent years. There is a desire to establish a technique to determine the state-of-health of the battery in an attempt to improve the reliability and service life of the battery system. The focus has been on VRLA batteries, primarily because of the inability to visually inspect the internal element, and the difficulty in predicting potential individual cell failures.

Lead-acid batteries naturally degrade as they age. One effect of this deterioration is the increase in resistance of the various paths of conductance of the internal cell element. The internal ohmic test units are generally designed to detect this internal change. These commercially available instruments input an electrical signal and interpret the reflected signal in various manners, ultimately linking the signal to the internal resistance. They are commonly used to test a battery when new, and then periodically during the life of the battery. When the baseline reading begins to deviate beyond a pre-determined level, it is presumed that the battery is deteriorating internally. The term “internal ohmic testing” has been used to encompass the various techniques that are used - conductance, impedance or resistance.

Although these instruments vary in their input and reflected signal interpretation techniques, the readings are generally interpreted in the same manner. As a screening technique, they are used to detect a cell that deviates from the main population. Additionally, these devices are used to track trends over time in the internal ohmic readings. Most prior studies have focused on correlating these readings to discharge capacity performance.

This study attempts to quantify the effect of common product variations and defects on internal ohmic readings. VRLA batteries were intentionally constructed with internal defects, thus allowing one to determine the ability of the various commercial ohmic devices to detect known defects. Various internal defects in increasing degrees of severity were introduced into the cells in each of the major design components – plates, separators and electrolyte. Additionally, capacity discharge testing was performed to quantify the effects of the defects on the electrical performance of the cell.

It is proposed that the results of this study will provide a starting point in providing guidance to end-users on determining the value of commercial internal ohmic testers in detecting initial defects in VRLA batteries.

RESULT SUMMARY

This study shows that internal ohmic readings do indeed detect certain specific defects of a cell’s internal componentry. There was a clear correlation between internal ohmic readings and the degree of certain defects. Unfortunately, this study also uncovered the limitations of internal ohmic readings within this context. There were variations in the internal ohmic readings that were unrelated to the test variables.

Based on the preliminary results of this study, it is recommended that internal ohmic readings not be used as the sole acceptance criteria for lead-acid batteries. Using these devices as the exclusive acceptance criteria could give false positives and could also miss minor defects that have not yet affected the cell to the point of cell failure. It must be emphasized that this study was performed on a small sample set, and that the results of this study may not be representative of the general population. Additionally, the calculated average for each test group was used, which does not take into account the variability of the individual readings. It is suggested that further studies explore these limitations in more depth.

DESIGN OF EXPERIMENT

This study was conducted using a standard, commercially available 20-year, 2-volt, stackable VRLA cell. The model selected was one that is currently being sold into the industrial battery market, primarily the unregulated, telecommunications industry. The general features of this battery are consistent with the other major brands that compete in this same space. It is posited that the results of this study are applicable to other batteries of this same general design concept.

The basis of this study was the assembly of cells with known defects. Four major defect criteria were selected and are discussed below. All other aspects of the test cells were identical. Assembly was conducted within one single lot, using the same operators in the same time-frame. No known material shifts occurred within the test build.

1. Reduction in Positive Active Material (PAM)

    This defect was implemented by removal of pellet sections from the pasted plate. Amounts that were removed were 0%, 1%, 4% and 10% of the total pasted amount. A few of the actual defects that were simulated by this method include; underweight pasting of the plate during manufacture, improper curing of the plates during manufacture, damage to the plate prior to assembly and broken or corroded grid wires in the plate.

2. Reduction in absorbed glass mat (AGM) separator

    This deficiency was implemented by removal of sections of the AGM between one plate pair in the cell. The design of this cell has two layers of AGM between each plate pair. For this study, 0%, 10% and 20% of the AGM was removed from between the plates. The removal was done with only one of the two layers, as one layer was required as a minimum, to prevent a direct electrical short between the positive and negative plates. This defect simulated a torn separator that may occur during the cell manufacturing process.

3. Improper acid level

    For this short-coming, cells were intentionally underfilled and overfilled with electrolyte. This defect would not only cover errors during the manufacturing process, but processing errors as well. Improper initial charging of the cells could cause excessive electrolysis and gas release, resulting in an ‘underfilled’ condition of the cell. For this study, cells were filled with 90%, 95%, 100% and 105% of the design goal of the cell.

4. Paste lump

    Because of the fragile, non-woven nature of the AGM separator material, plate lumps can pierce the separator material and cause an electrical short over time. Deep cycling can accelerate this development. This anomaly was created by placing a paste lump on top of the plate, of the same thickness of the pasted plate. This would almost certainly pierce the separator over a short period of time and cause a hard, electrical short.

Once the test cells were assembled with the defect levels as indicated above, they completed their normal manufacturing process. Except for the known imperfections, these cells were believed to be normal and identical to each other in every other way.

Once the processing was complete for these test cells, they were then tested using three different, commercially-available internal ohmic testers of various vintages. All units were purchased independently by C&D, and there has been no collaboration or cooperation with any of the manufacturers of these test units for any portion of this study.

As a final point of comparison, all of the test cells were capacity discharged. All cells were floated within the same string and then discharged together. A temperature-corrected, constant-current discharge at the 8-hour rate to 1.75 ending voltage was conducted.

RESULTS DISCUSSION

SECTION I: OVERALL TRENDS

Once manufactured, every test cell was discharged. The entire group was discharged within one single string to ensure there were no variations in discharge current, environmental conditions or procedures. The measured capacity discharge performance of each test group is shown in Figure 1, from lowest to highest capacity. Each test group represents 3-5 individual cells. The control test lot was made as identical as possible to the test groups. The same material lots, operators and manufacturing processes were used. For ease in comparisons, the capacity of the control lot was normalized to 100 percent. This data manipulation allows for simple percentage determinations of the comparison lots as compared to the control group. As seen in this figure, there are distinct variations in performance between the different test groups. The significance of each individual test group is discussed below in Section II.

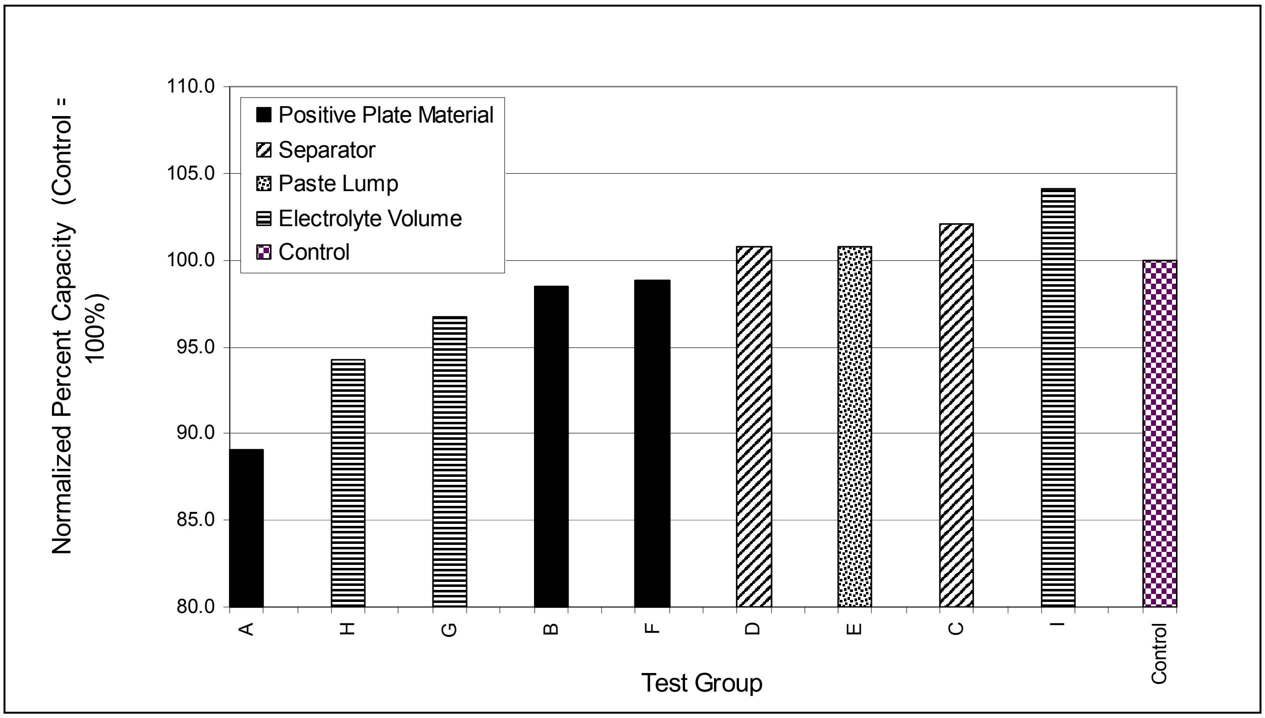

Figure 1. Measured Capacity of all Test Groups

All cell lots were tested with all three internal ohmic testing units. The comparisons of the average readings from these three units are shown in Figure 2. The readings for each unit were normalized such that the readings for the control cells were set to a value of 1. In this manner, the percentage shift from the control value is easily determined. Additionally, because the units of one of the test unit is based on conductance, and the other two are based on resistance, the inverse of the conductance readings was used so that the directional change in values would be consistent within all three test units.

Although several test groups (Groups B, F and D) had essentially the same reading values as the control, there were others (Groups H and G) with significant shifts. This figure indicates significant deviations of 5.4% lower and 21.8% higher than the control group. A further analysis of these test groups in regards to the type and degree of internal defect can be found in Section II.

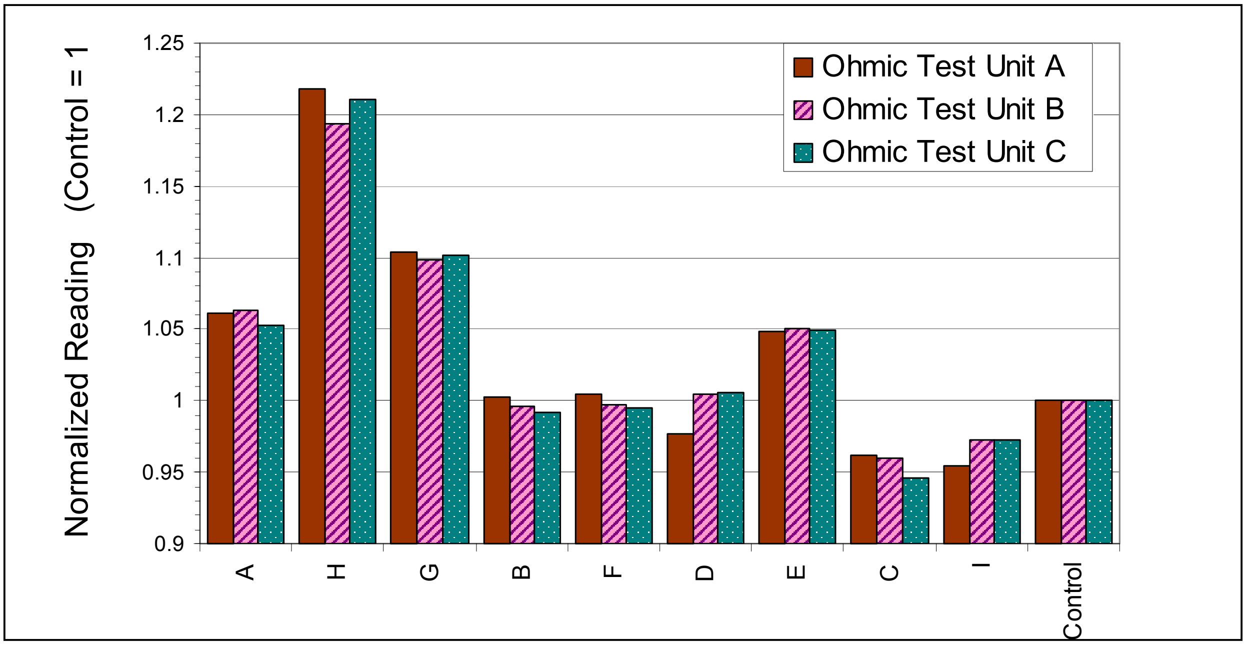

Figure 2. Internal Ohmic Readings of all Test Groups

Figure 3. provides one final analysis of the combined test groups. This figure shows the correlation between ohmic readings for all three testing devices verses the measured capacity of each test group. All three testing devices show close agreement with each other for all test groups, when looked at in a normalized perspective. For this figure, the ohmic readings for the control cells for each testing device was mathematically set to be 1.0. Other test values were then plotted as a fraction of this normalized value. A greater than 98% correlation coefficient was found between the normalized ohmic values of the three testing devices. However, the correlation coefficient of each of the ohmic data ranges with the discharge capacity values was only in the range of 60.3 to 64.9. The further analysis of the capacity correlation will not be discussed here, and is left to the reader for final interpretation.

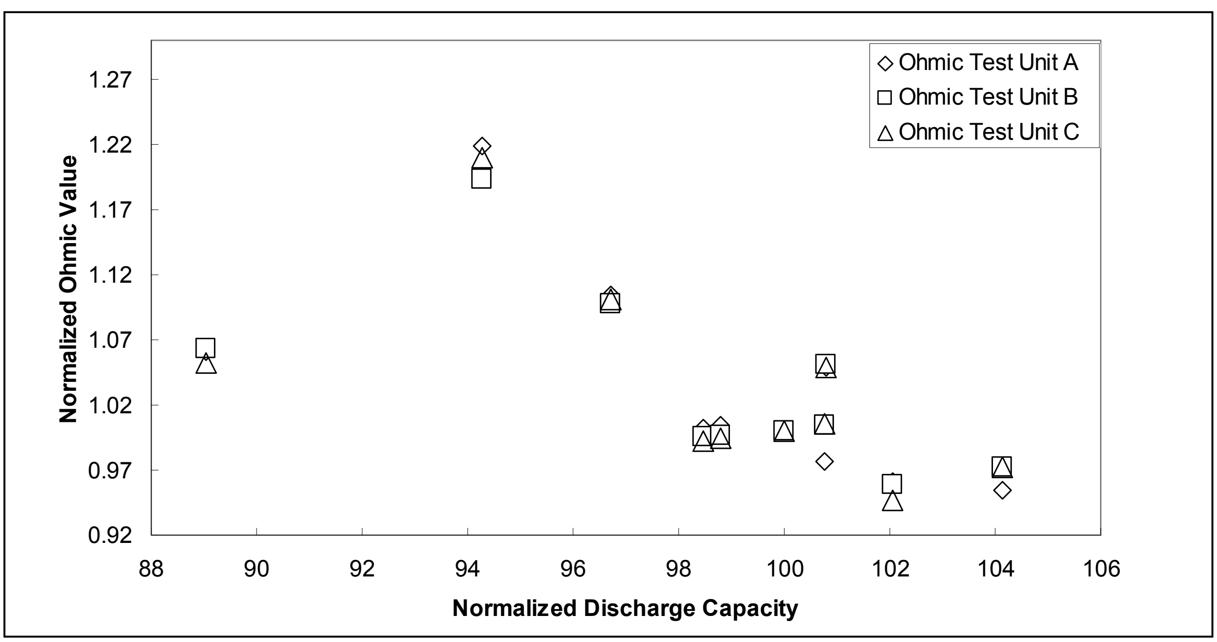

Figure 3. Ohmic Values vs. Measured Capacity of all Test Groups

SECTION II: ANALYSIS OF DEFECT CONDITIONS

The basis of this study was to determine the accuracy of detecting internal cell defects with commercially available internal ohmic testing devices. The individual analysis of each defect follows.

Positive Active Material (PAM)

By design, the limiting reagent in the chemical reaction occurring during discharge in a VRLA cell is the sulfuric acid in the electrolyte. With a design excess of plate active material, a reduction in PAM would not be expected to substantially affect discharge capacity until it fell below the amount to chemically balance the sulfuric quantity.

For this test, cells were built with reduced PAM in the amounts of 1%, 4% and 10% less than nominal. The ohmic test readings for these groups, as well as their discharge performances are shown in Figure 4. This data shows that there was no significant shift in the readings from any of three ohmic testers associated with the loss of 4% of PAM or less. However, at 10% loss of PAM, there was a significant shift of 5.3-6.5% of the baseline (control) reading. The discharge performance of each test group is shown in Figure 4, and indicates a trend in performance loss as the active material is decreased. Table 1 below summarizes the findings of this test group. This test shows that ohmic readings did not accurately detect minor active material losses of 4% or less, even though with this amount of PAM loss, there was a slight decrease in the discharge performance.

Test Group	Average Discharge Capacity	Average Ohmic Value
100% PAM	100	1.000
99% PAM	98.8	0.999
96% PAM	98.5	0.997
90% PAM	89.0	1.060

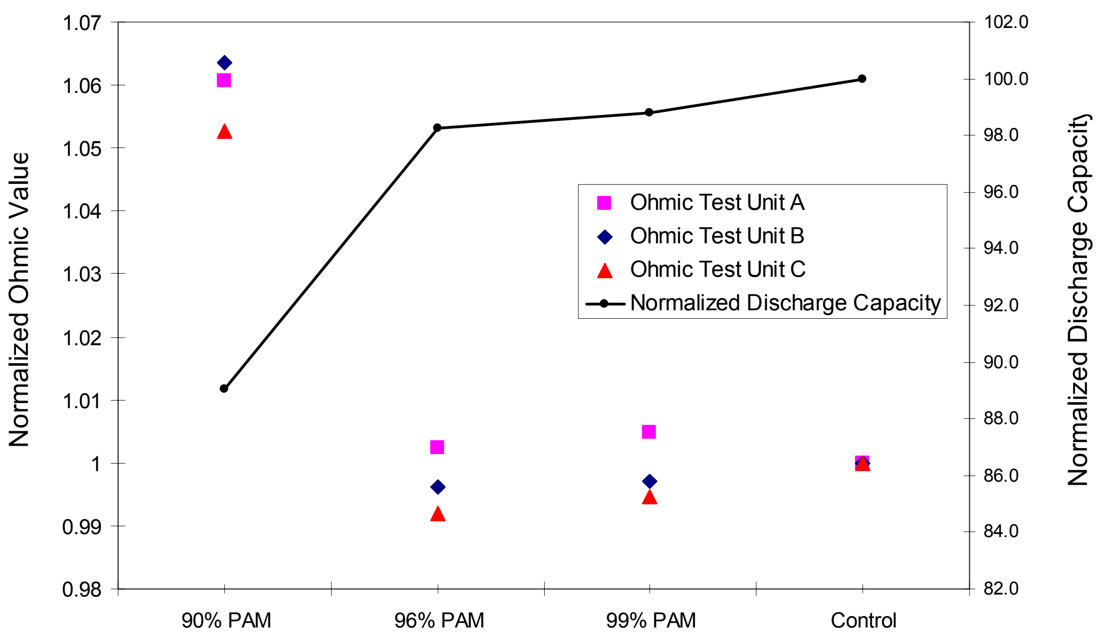

Figure 4. Ohmic Values and Discharge Capacity for PAM Test groups

Absorbed Glass Mat (AGM) Separator

Cells were built with two full sheets of AGM separator between each plate pair as the standard control. The separator material is a non-woven glass, with limited strength to resist tearing and damage during handling. Ten percent and twenty percent of one sheet was removed to simulate damage and tears to the separators that may occur during cell assembly and processing. Because of the high compression of the plates used in VRLA batteries, it is unlikely that tears and gaps in the separator will occur after cell assembly.

Figure 5 shows the ohmic readings obtained for the three AGM test groups. There was a small drop in ohmic readings at 10% missing AGM, with the ohmic reading essentially returning to the control baseline at 20% missing AGM. The cause of the shift at 10% has not be identified, although it does not appear to be random test variability. This unknown cause of ohmic variation should be noted well, as it is unsupported by known physical or chemical reasons.

Although the data is not conclusive, the preliminary assertion is that gaps in the separator of the extent introduced in this test cannot be detected by the ohmic testing units. Although the initial performance capacities of the cells were not compromised, this defect is important to detect early. Severely damaged or torn separators can result in electric shorts immediately upon cell assembly. It is believed that less severe damage provides a path of reduced resistance to ‘soft’ or dendritic shorts in the future. High cycling and deep discharge regimes increase the chances of these types of shorts developing in weakened separator sections. It is also believed that two thin sheets of separator verses one thick sheet will increase the resistance to dendritic shorts by interrupting the porous pathways through the glass.

It is asserted that the cells with missing AGM sections would fail early in their lives, and would not have been detected by the internal ohmic testers.

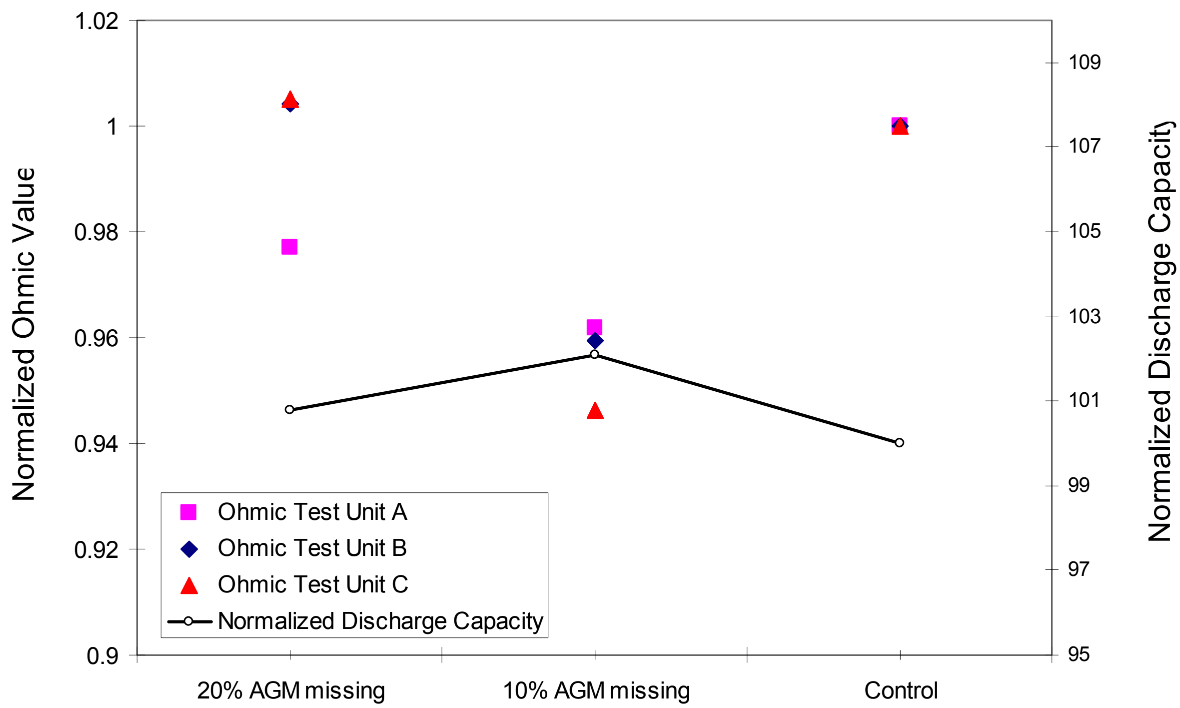

Figure 5. Ohmic Values and Discharge Capacity for AGM Test Groups

Electrolyte Level

By design, VRLA cells are physically undersaturated by a specific design amount, typically 3-8%. This is required to properly allow the recombination reaction to occur. With the sulfuric acid as the limiting reagent in the chemical discharge reaction, it would be anticipated that variations in acid quantity would directly and strongly affect the cell's discharge performance. This was shown to be so, as can be seen in Figure 6.

Cells were filled with 90%, 95% 100% and 105% of the design quantity of electrolyte. The same electrolyte batch and specific gravity was used in all cells. Cells were all filled at the same time to negate any temperature effects.

The ohmic values of these cells are shown in Figure 6. There was strong agreement by all three testing devices with each test group. Additionally, the percentage shifts in the ohmic values for each of the three testing devices were almost identical. Clearly, all devices were shown to be successful in quantifiably detecting electrolyte quantity within these test groups. By nature of the strong design dependence of performance capacity on electrolyte quantity, all three testing devices appear able to accurately determine performance capacity due to electrolyte quantity.

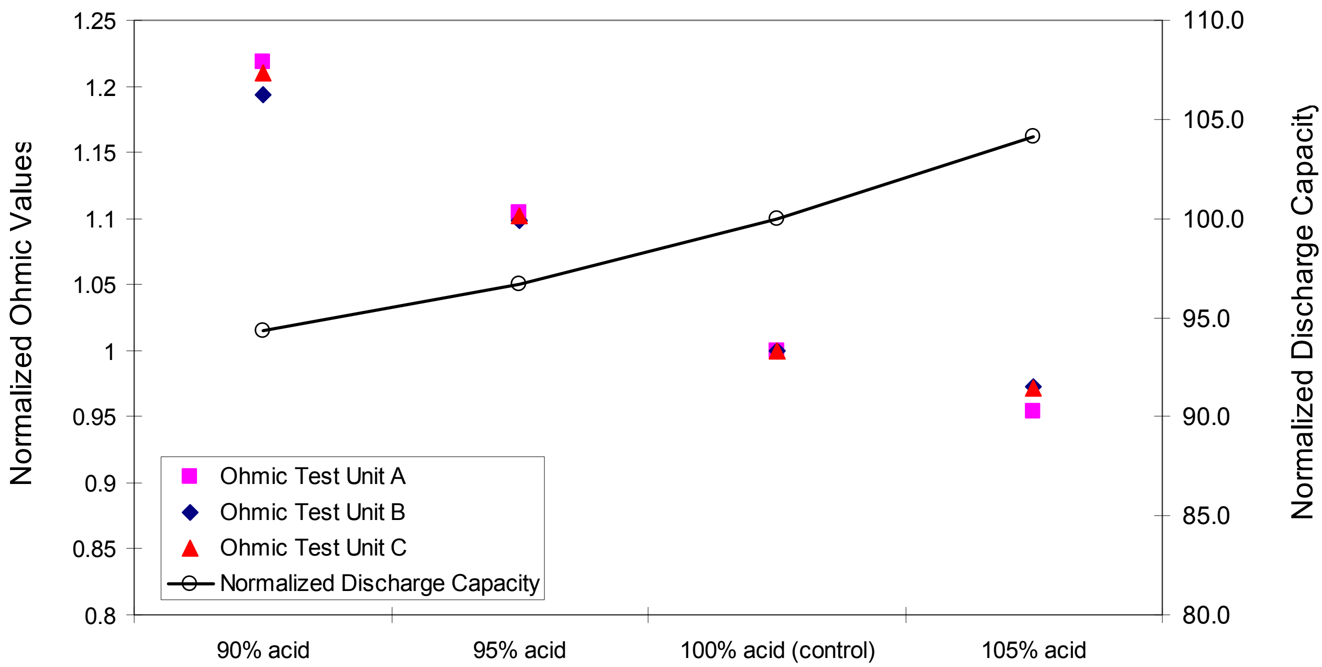

Figure 6. Ohmic Values and Discharge Capacity for Electrolyte Qty. Test Groups

Paste Lump

This last variable is generally accepted to be an important factor in production of reliable and long-lasting cells. Because of the high compression of the VRLA cells, and the soft, non-woven nature of the AGM separator, foreign matter between the plate pairs can easily lead to electrical shorts. Most battery manufacturers expend significant energies in ensuring smooth, lump-free plate surfaces.

This section was designed to determine whether these instruments could detect a significant lump on the plate surface. Although the actual duty cycle and environmental conditions would greatly affect the development of a short, the lump was large enough that it would almost certainly have caused failure of the cell within its first year or few years of life. During the cell assembly process, it was determined that the AGM separator was strongly compressed at the lump, but was not pierced or torn during assembly.

The discharge performance of the test group with paste lumps is shown in Figure 7, in comparison to the control cells. No drop in performance was seen indicating that the paste lump had not yet pierced the separator or grown into an electrical short. Interestingly, the ohmic readings from all three testing devices increased approximately 5% in a very consistent manner.

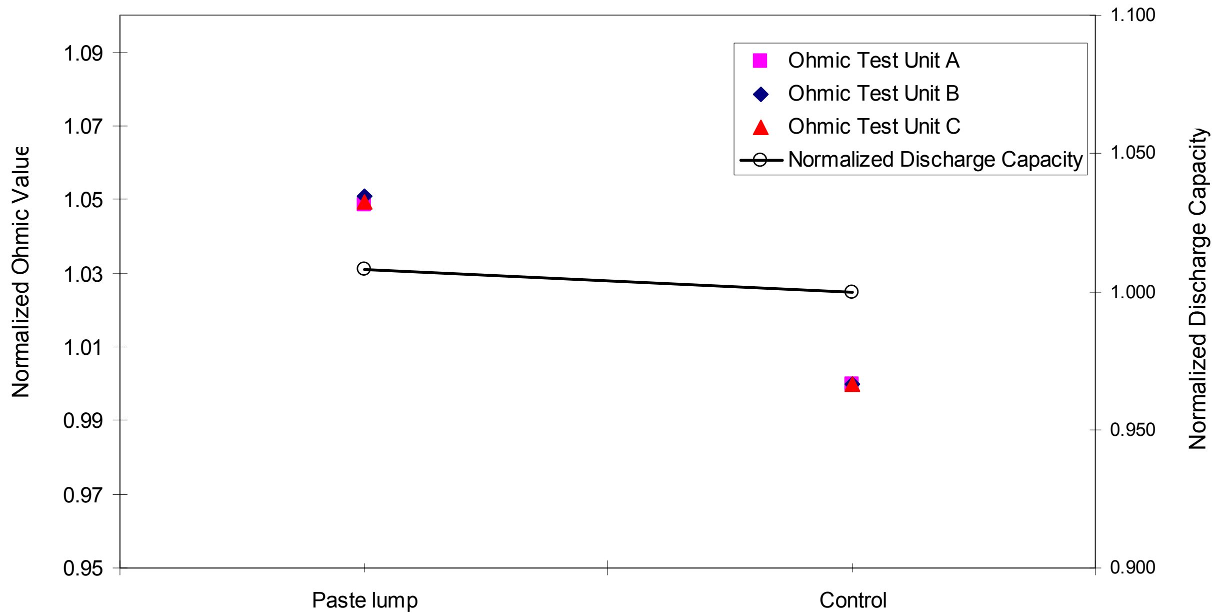

Figure 7. Ohmic Values and Discharge Capacity for Paste Lump Test Groups

CONCLUSIONS

This study was designed to determine the ability of commercially available internal ohmic measurement devices to detect and quantify internal cell defects. Analyzing the data in a normalized manner allowed direct comparisons of this information. It was found that there was greater than 98% correlation between the three ohmic testers, with percentage deviations from baseline that were extremely similar to each other. Therefore, for the conditions of this test and the specific test groups within this study, the three different testing instruments performed similarly within each defect lot.

A summary of the results, are shown in the Table below.

Defect type	Preliminary Conclusions of Ohmic Testing
Positive Active Material	• Cannot detect small defect level (<4%) • Could detect large defect level (10%)
AGM Separator	• Could not detect AGM defects up to 20% of one layer
Electrolyte level	• Could detect varying electrolyte levels (90% to 105%)
Paste lump	• Could detect large plate surface lump prior to becoming electrical short

In summary, regarding the use of the three widely used, commercially-available internal ohmic testers, they appear to have important but limited usefulness and accuracy in detecting internal defects

This study revealed that the ohmic testing was able to quantifiably detect variations in electrolyte levels. This is not totally unexpected, as the electrolyte is a major contributor to the internal resistance of the cell. This is a very valuable detection for most VRLA batteries. Since VRLA batteries are typically electrolyte-limited in their design, the discharge capacity is often directly related to the electrolyte level. And so, the changes in ohmic reading that are due to electrolyte levels can be directly correlated to the discharge performance of the cell. This study also showed that a sizable paste lump could be detected prior to developing into a short. This is an important item and is worthy of further studies to verify these results.

There were also limitations uncovered in these testing methods. Certain internal cell defects that can cause loss of capacity were not picked up by these devices. Specifically, these devices failed to detect small, but substantial changes in the positive plate active material content. This indicates that the increase in electrical resistance of the cell was not changed significantly by the loss of the PAM pellets. Since the material in the positive plate is clearly required for the discharge reaction, the implication is that the cell discharge performance could be compromised without detection by the ohmic testing devices. Only when the plate material defect was very large (approaching the loss of an entire plate within a cell) were the testing devices able to detect a significant deviation from baseline.

The ohmic testers also failed to detect substantial defects in the AGM separator. This defect would be expected to eventually develop into an internal electrical short, causing infant mortality of the cell. In this case, the cell would appear to be perfectly healthy by all measurement methods (including a capacity discharge), yet would be expected to fail prematurely.

RECOMMENDATIONS

This study was intended to aid battery users in determining the value of using internal ohmic testing as a defect-detection method. Clearly, this testing is able to detect certain internal variations and such variations often indicate an internal defect. As such, they can provide useful clues to a cell's health. However it should be recognized that there are defects that are not detectable by these methods, and that if used, these ohmic methods should be complemented by other inspection methods as part of a comprehensive inspection plan. Further studies are recommended to pursue the investigation of this topic.

ACKNOWLEDGEMENTS

The authors would like to thank Allan J. Williamson and Jerry Rogers for their valuable contributions to this paper. Additionally, the staff of the Leola Production Facility, and Charlie McCarter and Elvin Gehman, in particular, were instrumental in the success and completion of this study.