Failure of VRLA Batteries: Material Aspects

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Abstract

Valve Regulated Lead Acid (VRLA) batteries have widely been used as energy storage devices in small and medium sized UPS systems for more than 20 years due to their higher power density and lower capital costs compared to traditional flooded cell solutions. In service, however, negative strap corrosion is still found to be the predominant cause of rapid and premature failure of the VRLA batteries. This failure can normally result in not only the increased costs of maintenance and replacement but also the decreased reliability level of the energy back-up system in emergency case. Therefore, the objective of the present study is to explore the root cause of negative strap corrosion of the VRLA batteries in terms of their chemical composition, metallurgical states. The results turned out that the negative strap corrosion preferentially occurred on a negative post, particularly at the connected interface between the lug and strap. The galvanic and intergranular corrosion attack was evidently found. Additionally, the formation of intermetallic compounds at grain boundaries was a key role in the rapid penetration of corrosion into the negative strap.

Keywords: VRLA battery, Negative strap corrosion, Pb alloys,.

1. Introduction

VRLA or maintenance-free battery is normally considered as a energy storage and back-up device used in many industrial sectors, e.g. telecommunication, data center, power generation etc., where the reliability of power supply is very critical and the use of flooded-type battery is restricted.[1-2] In many applications, failure of battery during service is a very serious issue because it causes lack of reserved power and interruption of user's equipment and systems. Negative strap corrosion, occurring at the negative component of battery, was evidently reported to be the most important problem in the VRLA battery due to the rapid rate of metal dissolution eventually causing the complete separation of the negative component. Subsequently, this resulted in the improper performance associated with open circuit in the battery.[1-3] The mechanism of negative strap corrosion was attributed to galvanic corrosion caused by insufficient wetting with bulk electrolyte at the upper parts, strap, of the negative component. This resulted in substantial voltage losses (IR drop) across the electrolyte path,causing the strap to become unpolarized (not cathodically protected). In addition, the effects of alloying elements and microstructure formation strap could also be the significant factors accounting for the acceleration of corrosion in the negative strap. Therefore, the present study aims to investigate the root cause of failed VRLA battery in connection with metallurgical aspects.

2. Background Information

Fig.1 Failed VRLA battery caused by the negative strap corrosion.

In this case, the battery distributor company found improper performance of a power back-up battery system used in a telecommunication substation. This battery system was in service for 0.5-1 year in service and consisting of a series of VRLA batteries. In the manufacturing process, a hand-burn soldering technique was used to fabricate the Pb-alloy strap joined to the lug.

After the occurrence of failure, the preliminary investigation was conducted by the distributor to find the separated components in the battery. Fig. 1 shows a failed VRLA battery caused by the negative strap corrosion, which is used for the failure investigation.

3. Analytical Procedures and Results

3.1 Visual Inspection

From the visual inspection, it indicated that the negative strap is entirely covered with by white corrosion products. In addition, a crack is found at the interface, joined line, between the strap and lug as shown in Fig.2.

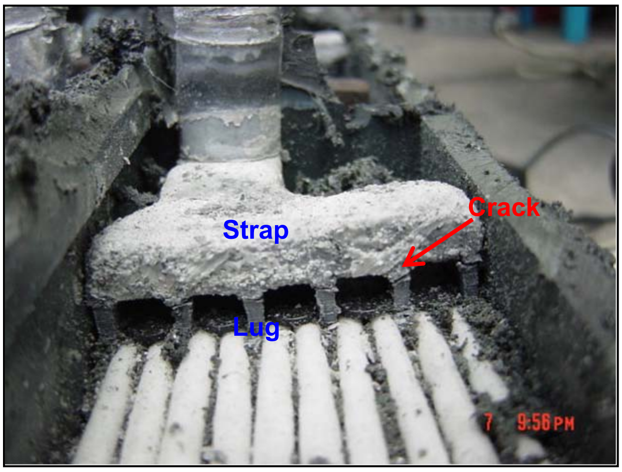

Fig.2 White corrosion products and a crack occurring on the negative strap.

3.2 Macrostructure Examination

As shown in Fig. 3, the lower area of strap adjacent to the lug has a relatively small grain size with respects to the upper areas. Moreover, more severe corrosion is obtained for the areas showing the fine-grain structure, causing the obvious separation between the strap and lug.

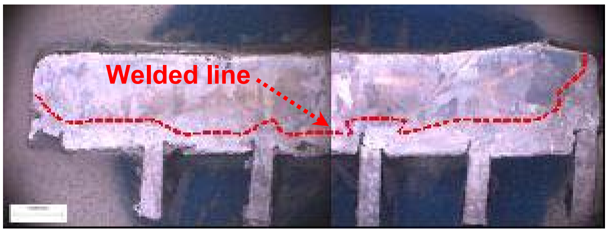

Fig. 3 Macrostructure of the failed negative strap.

3.3 Microstructure Examination

Fig. 4 shows the microstructure of the strap at the area adjacent to the completely separated lug. It can be seen that this region has the relatively small grain size with respects to the other regions. The elongated shape of grain structure along the heat transfer direction is obtained for that region.

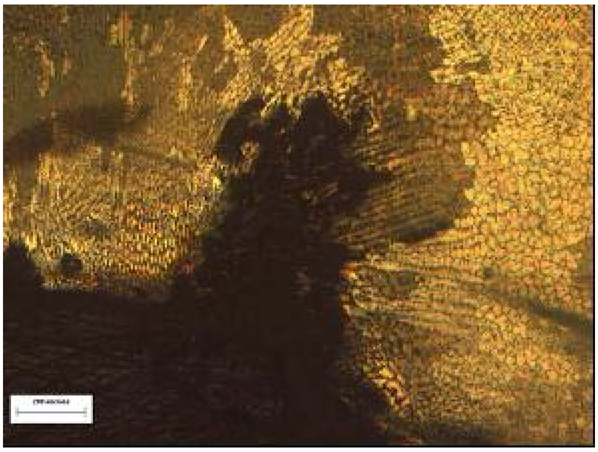

Fig. 4 The microstructure of the strap at the point of separation from the lug

At the joint between strap and lug, intermetallic compounds and intergranular corrosion are observed in large area as shown in Fig. 5. Furthermore, corrosion normally propagated from the external surface of the joint between strap and lug as shown in Fig. 6.

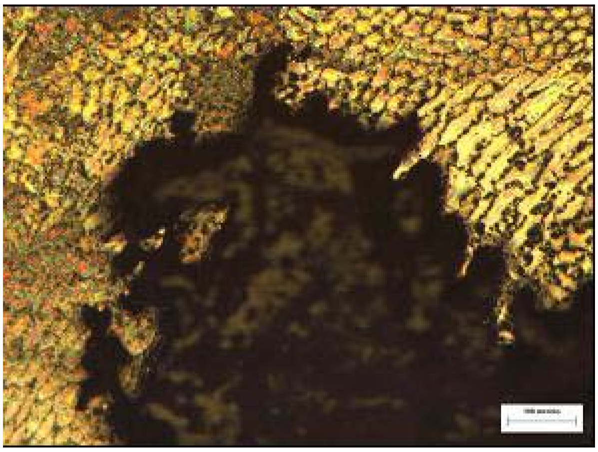

Fig. 5 Microstructure at the joint between strap and lug

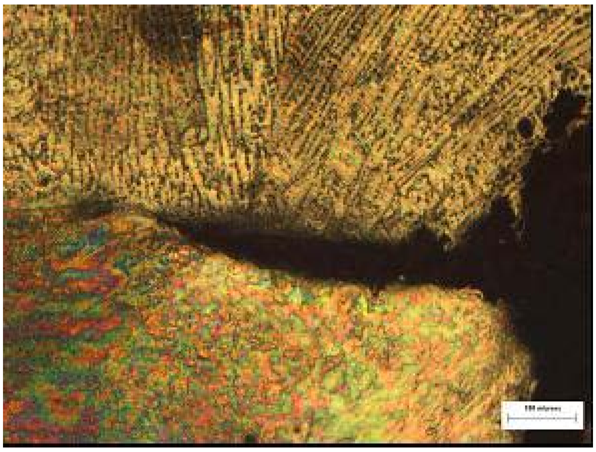

Fig. 6 The propagation of corrosion at the joint between strap and lug

3.4 Surface Analysis by SEM and Chemical Analysis by EDS

Surface analysis by SEM can confirm that the damage was initiated at the interfacial area between strap and lug, moreover, intermetallic compound were found precipitating along grain boundaries in the strap (Fig.7).

Investigation of the crack at high magnification shows precipitation of intermetallic compound at the edge and within the crack as shown in Fig. 8a. Chemical analysis by EDS (Fig. 8b) shows that the particles consist of carbon (C), oxygen (O), lead (Pb), tin (Sn) and calcium (Ca). On the other hand, Chemical analysis of intermetallic compounds at grain boundary of strap shows that they consist of carbon (C), oxygen (O), lead (Pb), tin (Sn), calcium (Ca) and arsenic (As) as shown in Fig. 9

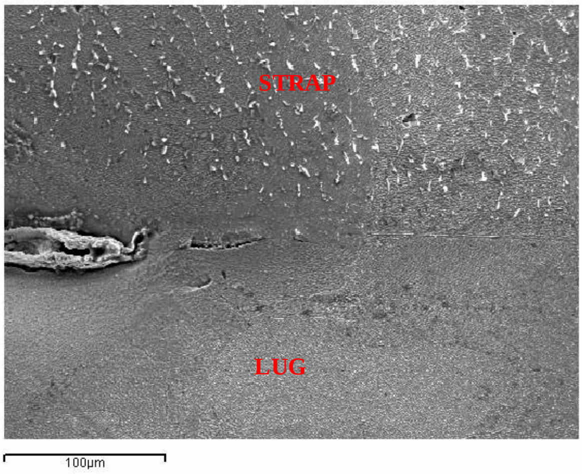

Fig. 7 SEM micrograph of the interfacial area between strap and lug.

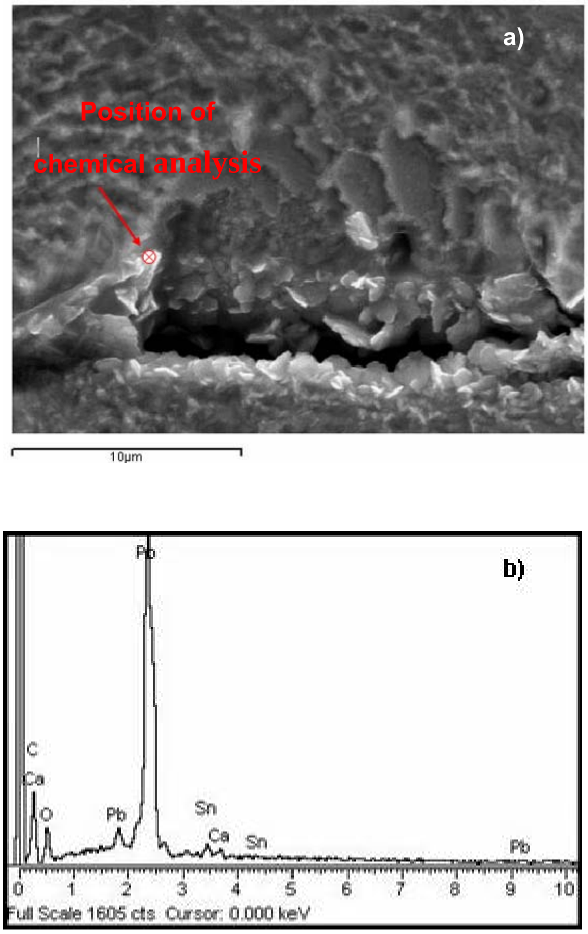

Fig.8 a) SEM micrograph of the crack and the position of chemical analysis. b) EDS spectrum

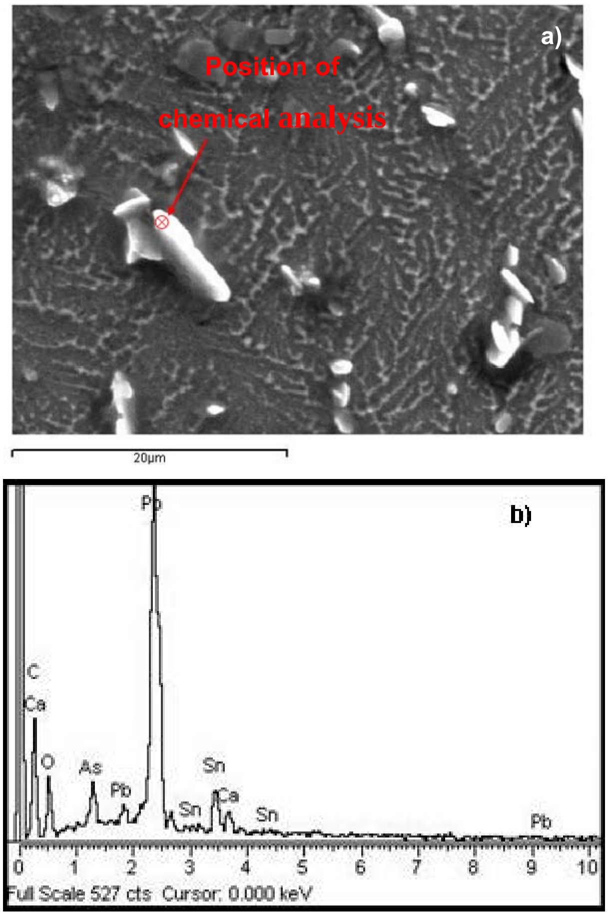

Fig.9 a) SEM micrograph of the intermetallic compound at grain boundaries and the position of chemical analysis. b) EDS spectrum

4. Discussion

From the macrostructure examination of the failed battery, it was found that the serious damage occurred at the weld line of battery, area where the melting between strap (lead-tin alloy) and lug (lead-calcium alloy), especially, the interface area between strap and lug. When examining the grain orientation at the joint between strap and lug, grains were found oriented along the direction of heat transfer. This grain orientation reduces the interfacial strength between strap and lug and increases the risk of intergranular corrosion [1-3].

Examination of microstructure of the damaged strap and lug showed that the interface between strap and lug was the initiation site of corrosion in intergranular mode. Fine intermetallic compounds were found in the intergranularly corroded area. Chemical analysis shows that the precipitates consist of the following contaminating elements, tin (Sn), calcium (Ca) and arsenic (As) (additive for grain refinement). Precipitation might result from the mixing of molten strap and lug. This mixing decreases the solubility of calcium in lead alloys [2, 4-6]. In addition, lead, tin and calcium might react with one another to form intermetallic compounds that precipitated along grain boundaries [2]. Moreover, calcium dissolved in lead alloys reduces the intergranular corrosion resistance of lead alloys. According to those reasons, the tin content of strap should be lower than 0.75 wt.% [1].

5. Conclusions

Based on the results of failure analysis of the VRLA battery, the conclusions can be drawn as follows:

1. The interface between strap and lug was an initial site for corrosion which was propagated from the outer surface of the negative strap.
2. Intergranular corrosion was a key phenomenon to induce the failure of the negative strap corrosion.
3. At the interface between strap and lug, grains were oriented and elongated along the direction of heat transfer.
4. At the severely corroded area, the precipitation of tin-calcium-arsenic fine particles was found.

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