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Assessment of cast-on-strap joints of lead acid batteries

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Abstract

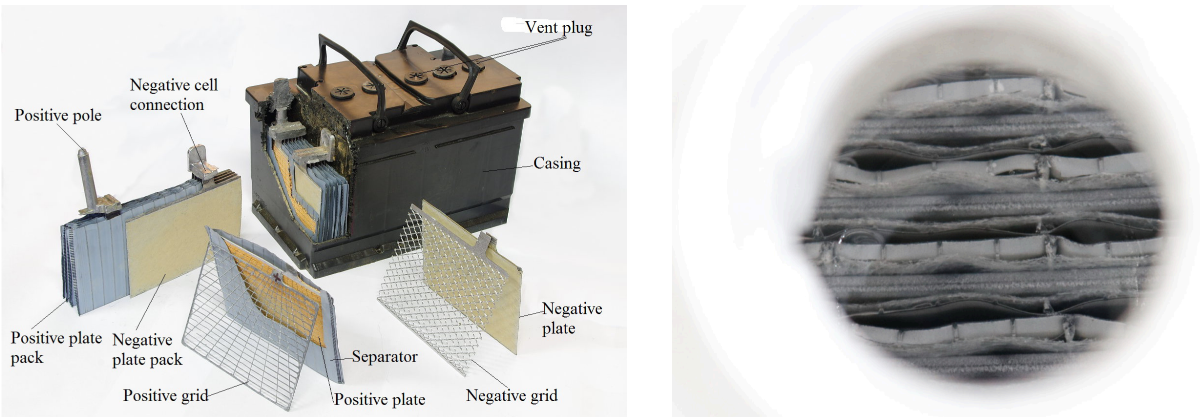
This paper presents the results of an examination of cast-on-strap joints of lead acid batteries with different discharge capacities. The galvanic joints of lugs of selected cells in lead acid batteries were analyzed. The study showed some defects that may occur in these joints. Examples of the defects that can affect battery lifespan were presented.

Keywords: *lead acid cell, electric parameters, capacities, cast-on-strap, joints*

1. Introduction

For over a century the lead-acid battery has been a successful product applied to energy storage purposes, emergency power, and electric and hybrid vehicles (including off-road vehicles). It provides energy for engine starting, vehicle lighting, and engine ignition (SLI). The widespread use of the lead-acid battery is accounted for by its many advantages like rich material source, high power, stable performance, technology and the ease of manufacture, high electromotive force, good charge and discharge reversibility and low price [1−3]. The possibility of failure caused by vibrations occurs in automotive application due to wear and tear of the road. These vibrations can result in fatigue failure, particularly between the cast-on-strap and pillar post leading to loss of electrical connection. The lead acid battery consists of the container, terminals, safety valve, and external vent plugs on the cells. A single cell is a set of alternating positive and negative plates separated by a piece of separator and immersed in sulphuric acid as an electrolyte. The positive (PbO_2) and negative (spongy lead) active material are spread on the lead alloy which is a current collector (grids) [4−6]. The construction of a lead acid battery is presented in the Figure 1.

Battery defects can happen even during the manufacturing processes and they cannot be totally eliminated. Some of them, due to their low harmfulness, are accepted or conditionally accepted. Optimization of manu-



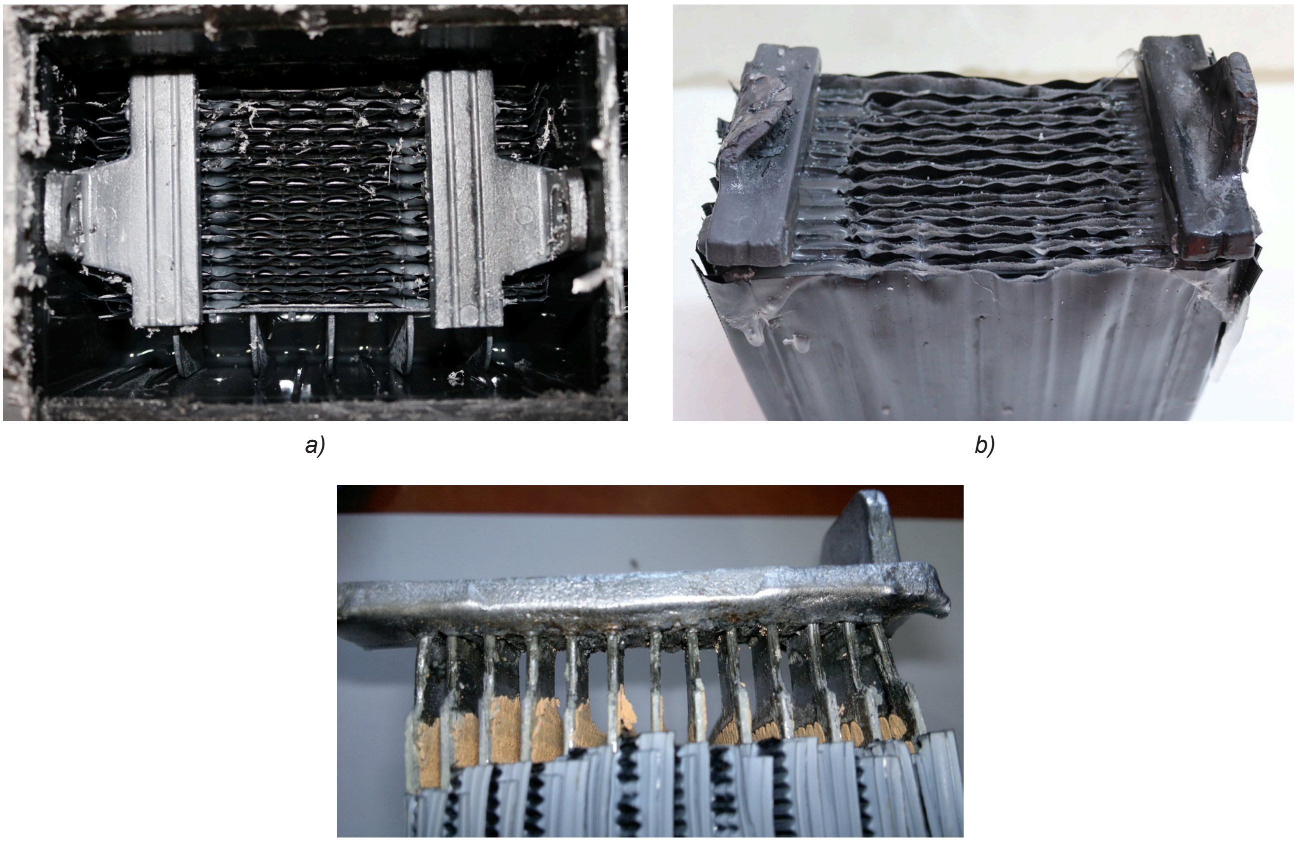
a) b)

Fig. 1. The construction of a lead acid battery (a) and view from above (b) [photo M. Budzyński and E. Jankowska]

facturing processes as well as minimization of rejected items if failed in quality or technology control are very important. It is crucial to know how a given defect may affect battery parameters and their exploitation. Some defects presented in this paper could lead to serious issues, for example a rupture of a plate connection when a battery's operations could result in its explosion. On the other hand some defects could remain unnoticed, for example minor differences in lugs-to-bridge joints. Usually, it is not common to seek positive aspects of defects, but in some respects battery defects could be beneficial. By defect analysis one could find a way to improve battery parameters, decrease lead amounts used in the manufacture and thereby diminish the emission of harmful substances to the environment. However, if a battery with the defects presented is accepted to the market it could bring some disadvantages like a lowered lifespan and the possibility of abrupt failures.

Cast-on-strap (COS) is a process of grouping individual plates of the same polarization (positive or negative) in each cell of a lead-acid battery. This process ensures the integrity of the whole components in the cell and an electrical connection between the individual plates with active mass [7−8]. The COS process involves immersion of the cleaned and stacked plate (positive and negative) lugs into a preheated mold cavity filled with molten lead strap alloy. It is followed by the cooling of the cast bridge. The joining occurs by partial melting of the lug surface which then fuses with the strap alloy in its liquid state. The COS joints must be characterized by adequate mechanical strength, not only the bridge itself, but also the bridge-lug connection, have good corrosion resistance and low electrical resistance [9−10]. The example of joints of lead acid battery shows in the Figure 2.

It is not possible to use universal parameters of cast-on-strap form for all accumulators due to thermal processes as well as differences in the mass ratio of plates (grids) to the mass of the lugs. Therefore, appropriate parameters for conducting the cast-on-strap process for an individual type of lead battery should be used. The quality of joints in the battery is strongly dependent on the careful construction of the cast-on-strap form and the control of the process variables. The quality of the cast-on-strap joints can be assessed by observing the macroscopic features of the cross-sectional characteristics of the lug-strap joints such as the meniscus, extent of fusion, gas and shrinkage porosity and lug melting [11]. The various parameters which affect the COS process, are the selection of an appropriate strap alloy compat-



a) b)

c)

Fig. 2. The example of positive and negative joints of lead acid battery [photo E. Jankowska]

ible with the grid lug composition, flux composition, lug penetration depth and others [12].

This paper presents the results of some joints, which were prepared in the production lines of lead acid batteries. The aim of this study was show the defects of the joints.

2. Methodology

In the first part of the study, bridge connections were selected from cells of lead acid batteries with different nominal capacities. The samples to be tested were taken from new lead acid batteries available on the market. The lead acid batteries were brand new. They were not laboratory tested. Examples of bridge connections from selected battery cells are shown in the Figure 3.

The set of positive and negative plates was removed from the selected lead acid battery cell, and then the bridges were separated from the set of positive or negative plates. The positive grids were made according to the punching and gravity casting technology, but the negative grids were made according to the gravity casting technology and expanded metal method. The thickness of punched positive grids was in the range of 0.60−1.00 mm, but the thickness of gravity-cast positive grids was in the range of 0.80−1.60 mm. In the case of negative grids, which were made according to gravity casting technology, their thickness was 0.80−1.65 mm and the thickness of grids made by the expanded metal method was 0.60−1.20 mm. All samples were subjected to a metallographic analysis, i.e. surface polishing and etching to show the macrostructure of the bridges (Fig. 4). The sample preparation steps included cutting the bridge, pouring it in an epoxy resin in the mold. The samples were made using the Stemers Pendemax-2 device and water sandpaper with decreasing gradation (grain from 60 to 1200). The samples were then polished using a corundum suspension. The so prepared samples were etched in a mixture based on acetic acid together with additives, and then rinsed in water and dried. In the next procedure, their macrostructures were evaluated.

a) b) c) d)

Fig. 3. The cast-on-strap positive and negative joints of a lead acid battery [photo E. Jankowska]

a)

b)

c)

d)

e)

f)

g)

Fig. 4. The examples of cast-on-strap joints of plates, negative – a), c), g) and positive – b), d), e), f) [photo E. Jankowska]

3. Results and Discussion

To evaluate the parameters of the galvanic connections of the joints a metallographic and visual analyses of the samples were necessary. The joints lugs-bridge are shown in Figure 5.

It is clearly visible that the position of the lugs is correct. There are no air bubbles or other possible defects when immersing the lugs in the bridge system. OT3 type alloy can be used for immersing the lugs in the bridge. This type of lead alloys has an antimony content of 2.5−3.5% and additives. The tested grids and lugs were made of lead-calcium alloys and antimony alloys with addition of tin. The examples of bridge joints with their defects are shown in Figures 6−7.

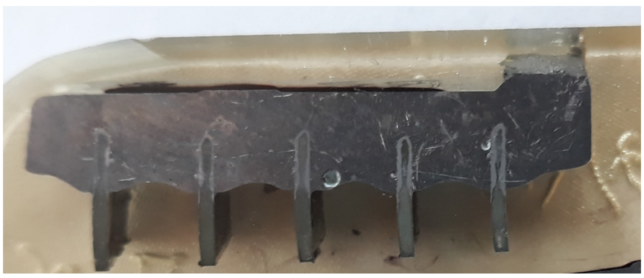
Analysis of joints (Fig. 6a−f) showed defects in the form of irregular distribution of the lugs. This weakens mechanical strength and decreases electrical conductivity. It can be concluded that a strong lug melting at its entire length decreases its strength parameters. It has been noticed that the strength of the connections between the lug and the bridge is affected by the cooling rate. Faster cooling results in the formation of a fine-crystalline structure, which positively affects the strength of the connection. The formation of larger crystals increases the risk of joint cracking. Moreover, higher cooling rates can result in an incomplete flux evaporation and the presence the air bubbles in the connection. At the lower cooling rate, no air bubbles are observed (Fig. 6c). Connection failure (Fig. 6d) reveals a gap where the electrolyte may pass through, which may lead to corrosion and thereby to poor mechanical strength. In addition, the strength properties are influenced by factors such as the amount of flux on the lugs, the purity of lugs, the rate of immersing lugs in the form, the temperature of the forms or lead and the speed of cooling.

A visual inspection of the quality of the samples showed that air bubbles can be observed in the examined joints (Fig. 7a−d). The presence of air bubbles may occur when the gas formed during flux evaporation could not escape towards the surface of the bridge due to a decreased speed of bubble transportation. This in turn is due to the low temperature of the alloy, which is associated with too little heat delivered to the alloy. It can also be related to too fast cooling or too much flux. After soaking the lugs in the flux, they must be dried before being immersed in the form of a bridge. The use of a suitable flux leads to the removal of the passive oxide layer from the flags, as in the case of mechanical cleaning of the lug surface. The use of flux or mechanical cleaning leads to slight roughness on the surface, which improves the contact of the lug with the bridge and also removes the passive oxide layer of lead on the lug.

Furthermore, it is worth paying attention to the meniscus while presenting the quality of joints. The meniscus should not be concave (Fig. 6f) because it could lead to slotted corrosion.

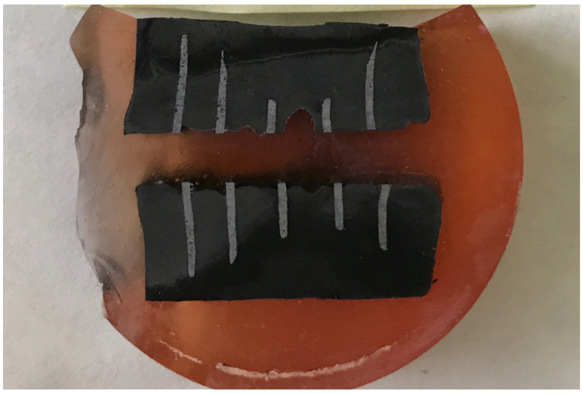
The type of flux is also important for the mechanical strength of the lugs. The connections of plates with lugs made of PbSe alloy with OT3 use a different flux than in the case of PbCa (PbCaSn) alloys also with OT3. The composition of the grid alloys has a significant impact on the quality of the connections. Lead-calcium alloys have a higher melting point compared to antimony alloys. The combination of lugs made of lead-calcium alloy requires more heat delivered to this system in order to obtain a good connection between the lug and the bridge. An inadequate amount of head supplied during the connection of lug – bridge may cause the deterioration of the properties of this connection.

a)

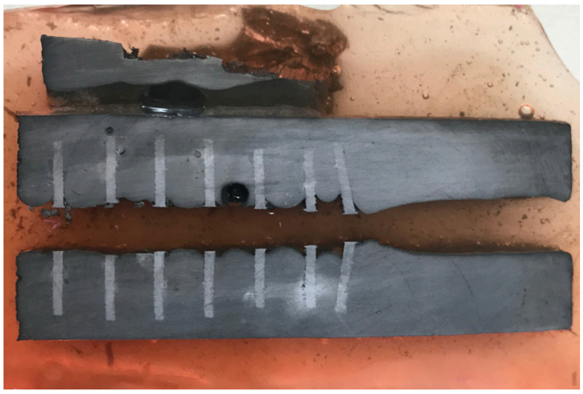


b)

Fig. 5. The positive plate pack's joints lugs-bridge [photo K. Frączek]



a)



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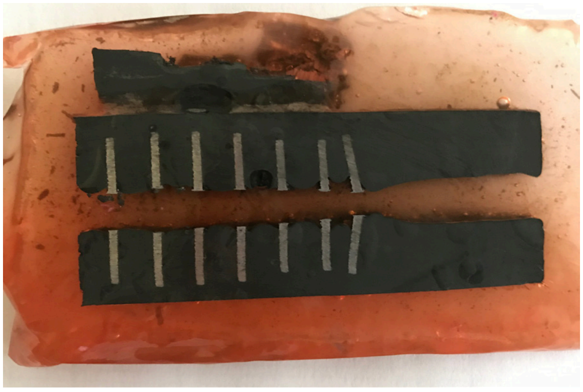

c)

d)

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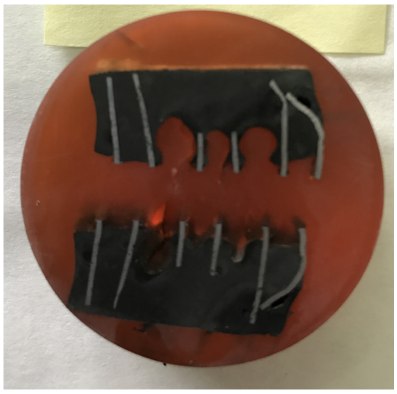
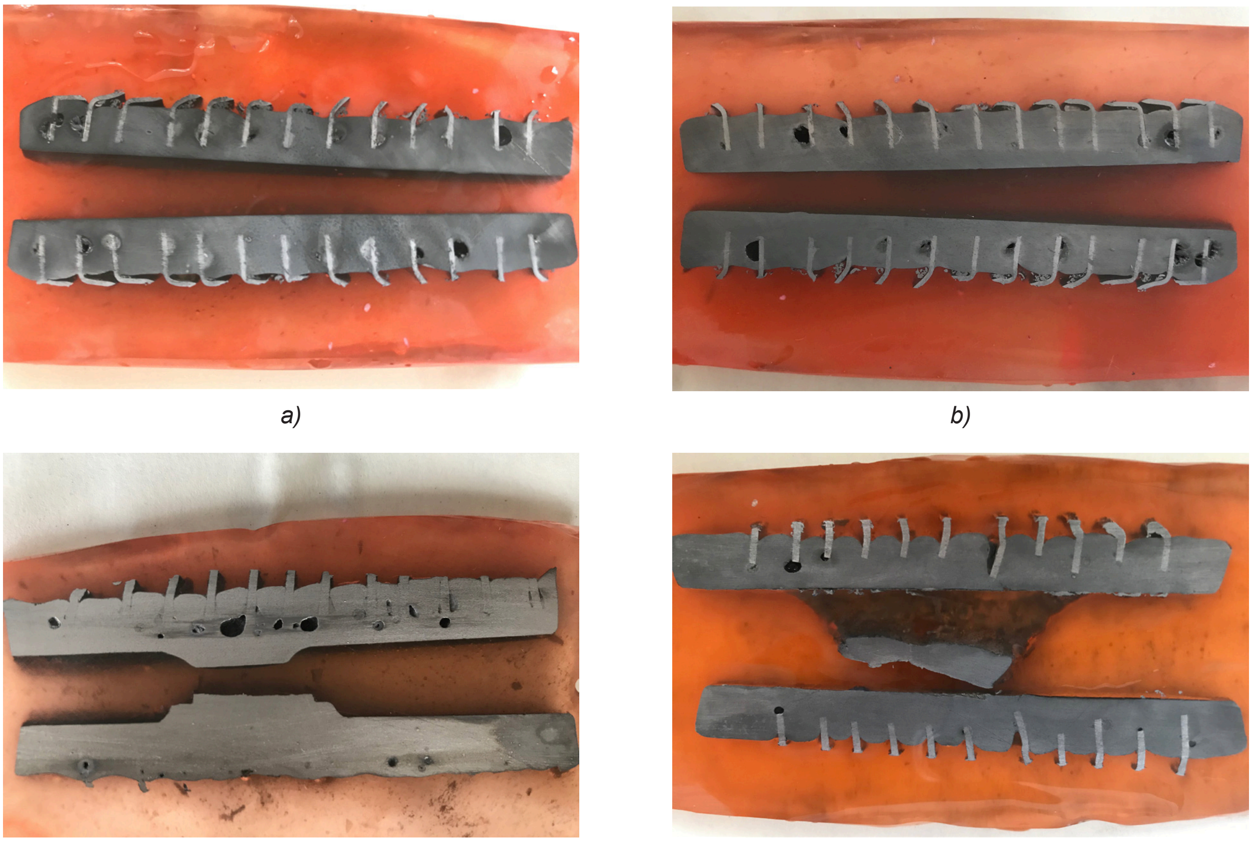


f)

Fig. 6. The examples of bridge joints in lead acid batteries, positive and negative [photo E. Jankowska]



a) b) c) d)

Fig. 7. Examples of bridge joins with defects, positive and negative [photo E. Jankowska]

4. Conclusions

The analysis of bridge joints of the selected cells of lead acid batteries with different nominal capacity revealed the occurrence of defects. Bridge connections were characterized by the occurrence of air bubbles, irregular distribution of flags and holes without lead. It can be concluded that production lines are still not optimized to prevent such defects. The tested systems were taken from new lead acid batteries that were not used. Visual analysis of the tested elements of selected cells showed no corrosion defects.

Acknowledgements

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