Journal of Energy Storage 13 (2017) 457–462

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Impedance spectra of enhanced flooded batteries for micro-hybrid applications

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ARTICLE INFO

Article history:
Received 17 January 2017
Received in revised form 6 July 2017
Accepted 10 July 2017
Available online 14 October 2017

Keywords:
Aging
Cycle-life
Enhanced flooded battery
Impedance spectroscopy
Lead-acid battery

ABSTRACT

The contribution presents impedance spectra of enhanced flooded batteries (EFBs) with reference electrodes for micro-hybrid applications. Batteries of different manufacturers are compared, also with respect to the temperature-dependency of their impedance spectra. Spectra fitting to suitable electrochemical equivalent circuits (EECs) allows a more thorough understanding of the physicochemical processes in these lead-acid batteries.

1. Introduction

The introduction of micro-hybrid applications in conventional passenger vehicles has stimulated a lot the development of improved lead-acid battery technologies like AGM (absorbent glass mat) batteries [1,2] and EFBs (enhanced flooded batteries) [3–8]. A further improvement requires a better understanding of physico-chemical mechanisms which also requires *in-situ* analytical techniques [9,10].

A potential candidate is electrochemical impedance spectroscopy (EIS) [11,12] which allows the real-time monitoring of battery performance if a suitable electrochemical equivalent circuit (EEC) is available that allows a good data interpretation [13].

In this contribution, we report about impedance measurements on different enhanced flooded batteries and their possible interpretation. The peculiarity is that we use reference electrodes to get data for anode and cathode, separately, and we compare a battery with special carbon-type material for increased charge acceptance [14] with a battery from another manufacturer that does not use these additives.

2. Material and methods

2.1. Batteries

Batteries under investigation were enhanced flooded batteries (EFBs) from two different manufacturers and with a nominal capacity of 59 Ah. The main difference between the two manufacturers is that one uses special carbons to improve battery performances [5,13,14] and the other does not. All batteries were equipped with hydrogen reference electrodes type Hyflex from Gaskatel. As for the measurement set-up, see Fig. 1.

2.2. Impedance measurements

All impedance measurements were done at 25 °C during battery cycling with batteries in LN2 container (cold crank current: 640 A EN) in a water-bath and with Digatron EIS-Meter equipment. Spectrum acquisition started always at 6 kHz and goes to at least 0.01 Hz. Due to measurement time restrictions (1 h measurement

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http://dx.doi.org/10.1016/j.est.2017.07.007
2352-152X/

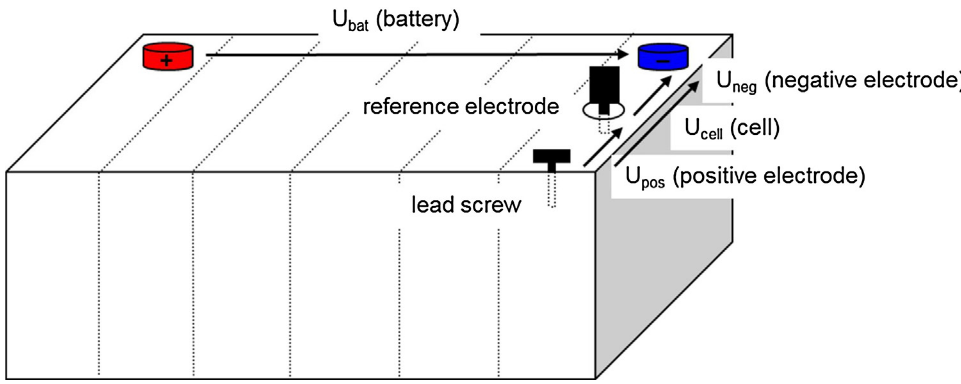

Fig. 1. Sketch of measurement set-up for impedance measurements on EFBs with reference electrodes.

time), the lowest frequency was given by the total measurement time. In general, 8 different measurement frequencies were used per decade, always including measurements for the positive and the negative half-cell. In the case of the negative half-cell, the measurement was done between the negative terminal and the reference electrode, and in the case of positive half-cell, it was done between the reference electrode and a lead screw in the intercell connector to the next cell.

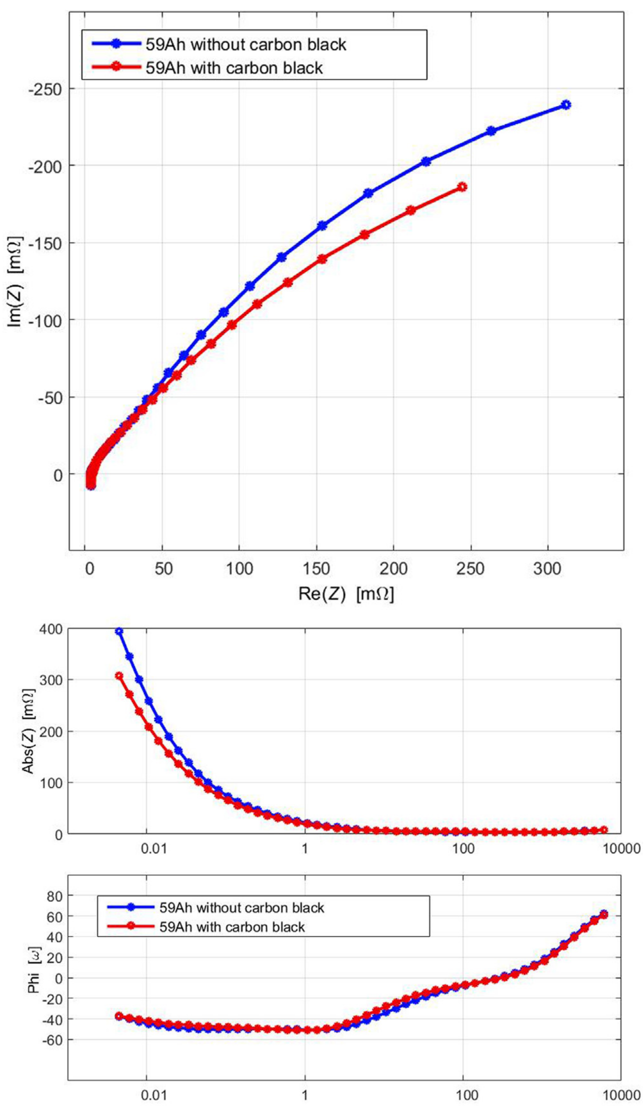

Fig. 2. Impedance spectra of both EFBs at 100% SOC (top: Nyquist plot, bottom: Bode plot).

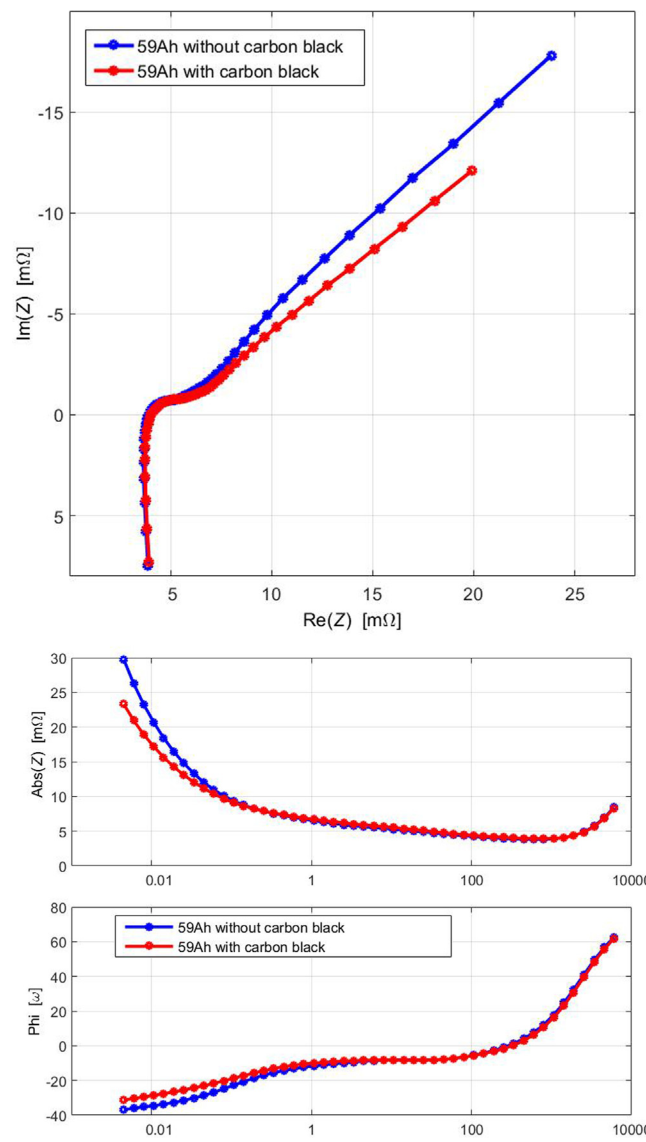

Fig. 3. Impedance spectra of both EFBs 50% SOC (top: Nyquist plot, bottom: Bode plot).