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Surface crack closing method for the carbon composite bipolar plates of a redox flow battery

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ABSTRACT

The vanadium redox flow battery (VRFB) is the most promising energy storage system (ESS) due to its safety, durability and scalability. The electrode and the bipolar plate are the most important components that affect the efficiency of the VRFB. Based on previous research, an expanded graphite-coating method for the composite bipolar plate of the VRFB was employed to reduce interfacial contact resistance between the electrode and the bipolar plate. However, damage to the coating layer of the composite bipolar plate during actual operating condition can reduce durability of the composite bipolar plate.

In this work, a surface crack closing method for the damaged composite bipolar plates of a redox flow battery was developed. To optimize the surface crack closing process, compressive tests of the expanded graphite were performed. The effect of the surface crack closing process was estimated by measuring the area-specific resistance (ASR) before and after an electro-chemical operation test. Based on the results of the analysis, the optimal surface crack closing process for the composite bipolar plate was suggested.

1. Introduction

Efficient large-scale electric energy storage systems are required for efficient electric energy management because the electrical energy crisis has become a significant issue in many countries due to the nuclear reactor failure in Fukushima, Japan. The vanadium redox flow battery (VRFB) is one of the most promising candidates as an energy storage system for renewable energy sources [1–5]. Fig. 1 shows the typical structure of a vanadium redox flow battery system. The vanadium redox flow battery system consists of a stack of liquid electrolyte tanks and pumps that deliver the liquid electrolyte through the stack. Electric power in the VRFB is stored electro-chemically between two electrolytes in four different oxidation states (VO^{2+}/VO_2^+ in the positive electrolyte, V^{2+}/V^{3+} in the negative electrolyte). Compared to conventional secondary batteries such as lithium batteries and lead-acid batteries, the VRFB has a long life cycle and a decoupled design advantage with respect to power and energy capacity because the former depends on the stack size and stack number and the latter depends on the amount of electrolyte.

However, the VRFB has a disadvantage of exhibiting a very low current density of 0.1 A/cm^2, which is approximately 1/10 that of a conventional proton exchange membrane fuel cell (PEMFC). For the VRFB to produce as much power as a PEMFC with the same number of stacks, the stack area, including the areas of the bipolar plate, carbon electrode and membrane, must be increased. A graphite bipolar plate measuring approximately 3 mm in thickness has been employed in conventional VRFBs. However, the graphite bipolar plate is vulnerable to breaking due to its brittleness, especially when the area of the bipolar becomes large.

Although the carbon composite bipolar plate has been employed to overcome the brittleness of the graphite bipolar plate [6], the carbon fiber composite bipolar plate also features several disadvantages, such as low electrical conductance and difficulty of mass production for the commercialization of redox flow batteries. The main cause of the low electrical conductance of composite bipolar plates is the high interfacial or surface electrical contact resistance due to the resin-rich area on the composite surface, as shown Fig. 2(a) [6]. The carbon/graphite hybrid composite BP, which features a soft expanded graphite coating on the surface of a carbon fiber polymeric composite, has been suggested to reduce the contact resistance of bipolar plates [7]. Carbon fibers in the carbon felt electrode may easily deform the expanded graphite on BPs with an increased contact area when the stacking

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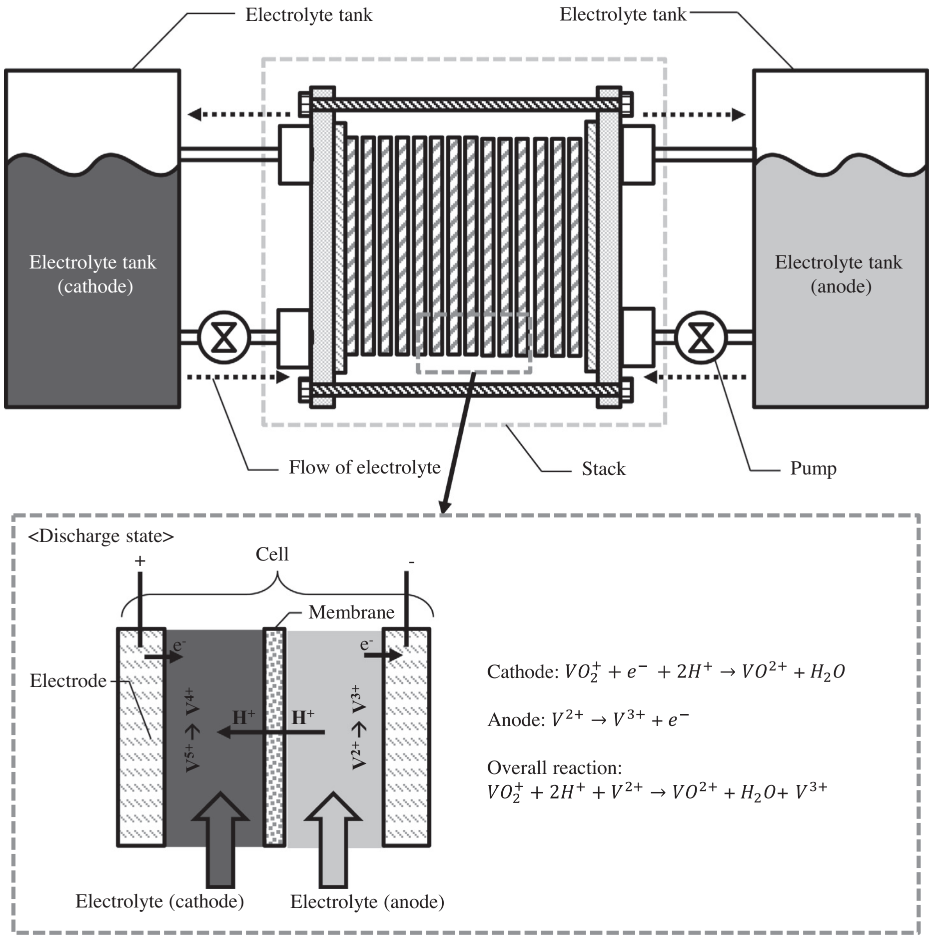

Fig. 1. Schematic drawings of vanadium redox flow battery (VRFB).

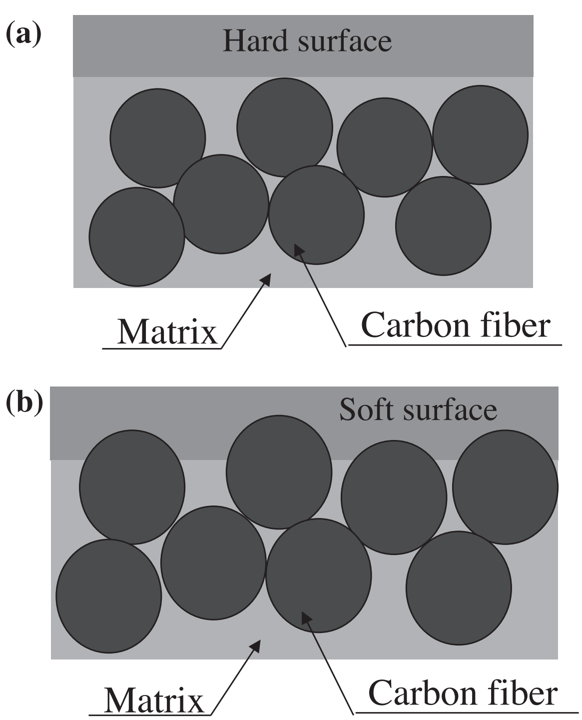

Fig. 2. Schematic diagrams of contact areas between the fibers of carbon felt electrodes and the surface of the bipolar plate: (a) hard surface (epoxy) of a conventional graphite bipolar plate and (b) soft surface (expanded graphite) of a carbon/graphite hybrid bipolar plate.

pressure is applied by the compression force of the end plates due to the low modulus of the expanded graphite coating layer of the BPs, as shown in Fig. 2(b). However, it has been observed that the expanded graphite coating layer is easily damaged during the peel-off of a thin graphite layer from a graphite plate with a sticky tape to control the thickness of graphite due to the excessive bending of the peeled graphite layer [8]. The damaged graphite coating layer might reduce the sealing ability of the carbon composite bipolar plate against sulfuric acid of high concentration.

In this work, a surface crack closing process for the damaged graphite coating layer of a bipolar plate for VRFB application was suggested to increase the chemical resistivity of the carbon composite bipolar plates. A compaction pressure was applied to micro cracks induced by tensile bending stress during the peel-off of a graphite layer to close the cracks. After the surface crack closing process, the electrical resistances of the graphite layers of the carbon composite BP were measured as a function of the compaction pressure applied during the surface crack closing process. Then, the optimal surface crack closing process of the graphite coating layer for the BPs was suggested, considering the durability of the coating layer of the BPs.

2. Fabrication of specimens

Due to the high electrical conductivity of carbon fiber, carbon fiber composite might be the only candidate material for composite bipolar plates among the several types of fiber composites that exist [9]. Therefore, two sheets of plain-weave-type carbon/epoxy