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Development of the light weight carbon composite tie bar

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ABSTRACT

Stacks of energy conversion systems, such as proton exchange membrane fuel cells (PEMFCs), are composed of several hundreds of components, and they are compacted with tie bars to decrease electrical contact resistance and prevent the leakage of fuels. Since the sealing performance deteriorates over long operation times due to creep deformation of the stack, it is important to maintain a consistent clamping force under the creep deformation of the stack for long-term reliability.

In this work, a light weight carbon composite tie bar was developed to replace the conventional steel tie bar. This new composite tie bar can achieve high elastic strain and provides a consistent compaction pressure to the stack over long operation time. To form the complex thread shape of the tie bar without compromising its tensile strength, different types of material were adopted for the thread and rod parts. A carbon fiber mat was used for the thread part because it has a higher drapability compared to other types of carbon fiber, such as unidirectional (UD) or the fabric type. The UD and fabric were adopted for the rod part for their high strength and elongation. Based on the tension test of the fabricated tie bar specimens, an optimum configuration of the carbon composite tie bar has been suggested.

1. Introduction

Since proton exchange membrane fuel cells (PEMFCs) are eco-friendly electrochemical energy conversion systems that have high power densities, they have been in focus as promising technology for automobiles and portable applications [1]. A PEMFC stack consists of several hundreds of cells for automotive applications. As shown in Fig. 1, each cell is composed of bipolar plates, gas diffusion layers (GDLs), a membrane electrode assembly (MEA), and gaskets [2]. Compaction pressure is applied to the assembled components by two endplates. Maintaining compaction pressure during operation is important for the PEMFC, because the compaction pressure closely relates to the performance and sealing of the system [3]. The clamping force could be applied using a hydraulic or pneumatic system or simply by tie bars [4]. The hydraulic or pneumatic system could provide a high and consistent clamping force to the stack. However, these additional systems make the PEMFC stack bulky, which is not suitable for the mobile application.

Conventionally, a number of long steel bolt tie bars are adopted to provide a clamping force to the stack in mobile applications [5]. However, deformations in the stack can occur due to a large temperature difference during operation, which can induce creep of the components. Because steel has a low yield strain (0.2%), the steel tie bars cannot provide a consistent clamping force when the components of the stack are deformed more than 0.2%. Therefore, an additional spring system is required to prevent loosening and to provide a consistent clamping force to the stack. However, a large number of steel tie bars and the spring system increase the weight of the system, which is unfavorable for the development of a light weight PEMFC.

Previously, various plastic bolts were developed based on thermoplastics such as polycarbonate, peek, polyethylene, polypropylene, polyvinylchloride, and nylon. Although these thermoplastic bolts are light, they have low strength and are weak against the creep condition due to their plasticity. Therefore, plastic bolts are selectively used in applications that require non-corrosive or insulating properties, such as chemical and electrical systems [5–7].

To increase the strength and reliability of the plastic bolts, fiber reinforced bolts were also developed [8–10]. However, the reinforced fibers were chopped short glass fibers and the volume fraction of the fiber was very low, which makes it unsuitable for tension joints such as the tie bar. Another application of the glass fiber reinforced composite bolt is the rock bolt, which takes the majority of the studies regarding the composite bolt [11–13]. Although the composite rock bolt is light weight and is corrosion

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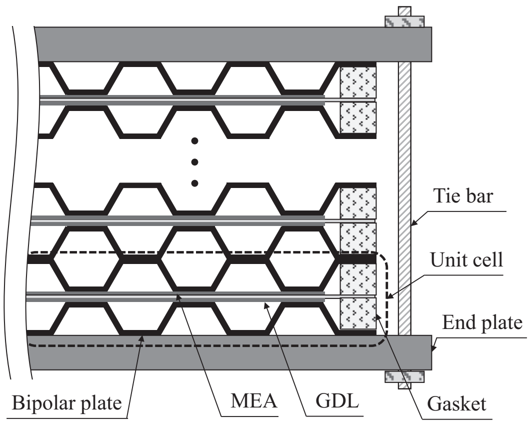

Fig. 1. Schematic diagram of the components for a PEMFC system.

resistant, its thread shape is designed to be rounded with a large diameter, which is not appropriate for the tie bar application.

In this study, a light weight carbon composite tie bar that has a high specific strength and a high failure strain compared to the conventional steel tie bar was developed. To fabricate the carbon composite tie bar, a fabrication method to form the complex thread shape was developed using the closed mold, which was developed for the autoclave vacuum bag degassing method. The newly developed carbon composite tie bar consists of a thread part and a rod part, which have been fabricated with different material configurations. For the thread part, a carbon fiber mat impregnated with epoxy resin was adopted to form the complex thread shape, because the mat type has higher drapability than the unidirectional (UD) or fabric types. For the rod part, the UD and fabric type carbon/epoxy prepreg with various stacking sequences was adopted for their high strength and high failure strain. Based on the tension tests, the effect of volume fraction of the thread part was investigated, and the optimum volume fraction of the thread part was suggested. Then, the failure characteristics of the tie bar specimens were investigated with respect to stacking sequence of the rod part.

2. Fabrication of the specimen

The bottleneck during the fabrication of the carbon composite tie bar is forming the small and complex thread shape. Both ends of the tie bar specimens were designed to have M8 with a thread pitch and height of 1.25 and 0.77 mm, respectively. However, the UD or fabric type carbon fibers were not able to follow the shape of the thread. The thread part that was fabricated with the UD or fabric type carbon fiber was filled with epoxy resin, as shown in Fig. 2. Therefore, in this study, the thread part of tie bar was developed using the carbon fiber mat, while the rod part was fabricated with the UD and fabric composite.

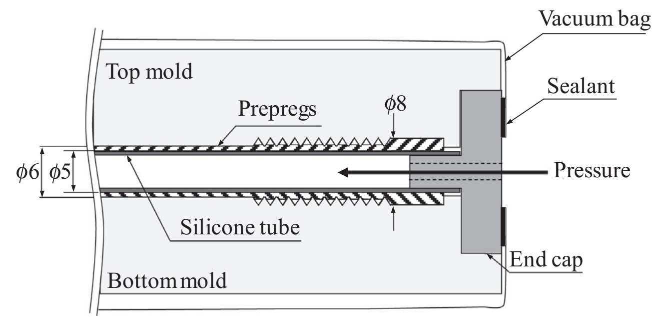

Fig. 3. Schematic diagram of the closed mold for the fabrication of the carbon composite tie bar specimen.

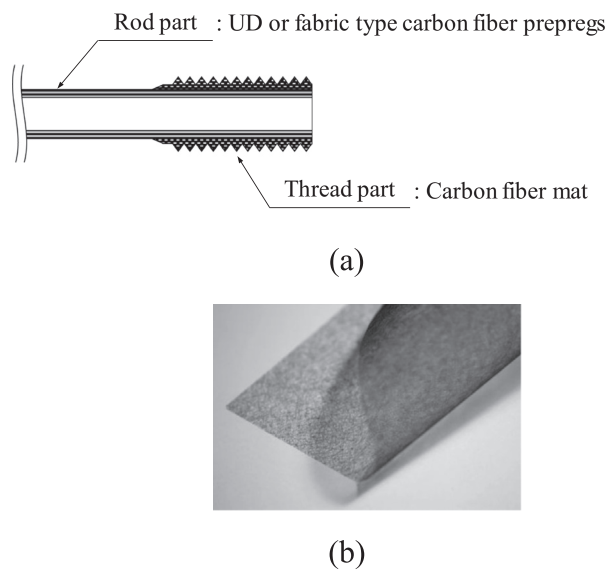

Fig. 4. Configuration of the carbon composite tie bar specimen: (a) materials for the rod part and the thread part and (b) carbon fiber mat with an areal density of 50 g/m^2.

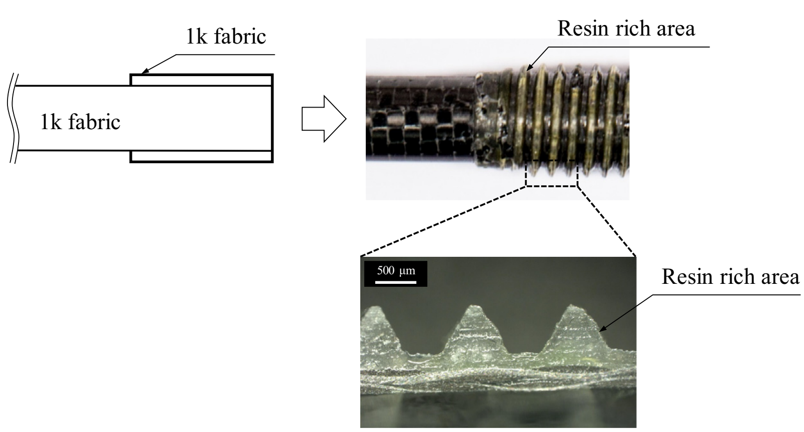

Fig. 2. Thread part that was fabricated with carbon fabric/epoxy prepregs.