Fabrication of stainless steel and TiC_xN_y composite for PEMFC bipolar plate

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Introduction

Recently, polymer electrolyte membrane fuel cells (PEMFC) have attracted considerable attention in the renewable energy industry on account of their high power density, low emissions, and low operating temperature[1]. A key determinant of the commercial realization of PEMFC is the bipolar plate. This component accounts for most of the total weight and cost of the PEMFC stack[2,3]. The material requirements for a bipolar plate are high electrical conductivity, high corrosion resistance, low gas permeability, low weight, easy machining, and low cost[4]. Stainless-steel is considered to be one of the most promising candidate materials that can be used as a bipolar plate instead of graphite because of its high electrical and thermal conductivity, ductility, low gas permeability, and low manufacturing cost. On the other hand, stainless-steel bipolar plates exhibit low corrosion resistance in the acidic environment that is typically present in fuel cells. The corrosion of stainless steel leads to the formation of a passive oxide film on its surface that increases the interfacial contact resistance and degrades the fuel cell performance[5].

Experimental

fabricate titanium carbonitride powder

1) reaction of a solution of liquid metal chlorides ($TiCl_4$+xC_2Cl_4) with sublimate magnesium nitride (Mg_3N_2),

2) formation of the fine titanium carbonitride ($TiC_{0.7}N_{0.3}$) particles by the reaction of the titanium and carbon released from chloride reduction of magnesium dissociated from Mg_3N_2 and the identical nitridation dissociated nitrogen from magnesium nitride,

3) removal of the secondary phases of liquid $MgCl_2$ and excess Mg_3N_2 by a vacuum heat treatment. In order to fabricate $TiC_{0.5}N_{0.5}$, the mass ratio of C_2Cl_4 in the initial mixture must be 2 times less than the process to fabricate stoichiometric titanium carbide powders. In this case, there will be formation of $TiC_{0.5}$ phase only, and the rest vacancy will be occupied by the atoms of nitrogen, contained in Mg_3N_2.

spark plasma sintering

The developed TiC_xN_y powders were consolidated together with pure stainless steel (STS 304L) powders by Spark plasma sintering (Dr. Sinter 1030, Sumitomo Coal Mining Co. Ltd., Japan). The weight ratio of TiC_xN_y powders and STS powders were chosen to be 95:5 weight ratios. During the consolidation of powders at SPS, heating rate was 200 ℃/min and the pressure was 10 KN. Sintering was done at 900℃ during 10 minutes under Ar-4%H_2 gas atmosphere. During the cooling time, the pressure was increased up to 20 KN in order to keep the as-sintered density of the specimens. The heat treatment of the sintered specimens was also conducted in SPS apparatus, and heating rate was 200 ℃/min, and the specimens were annealed at 850℃ for 30 minutes at Ar-4%H_2 gas medium.

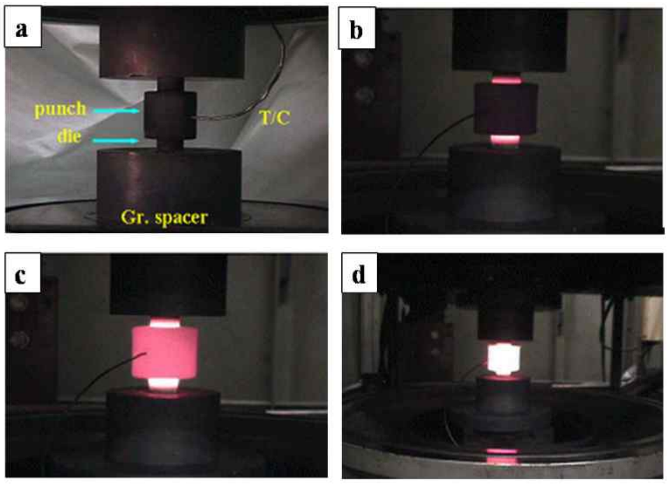

Fig. 1 The steps of the sintering in SPS: a) placing the mold, b-c) heating up to required temperature and d) holding

Result and Discussion

Fig. 2(a) demonstrates the microstructure of the developed powders. It was observed that the powders had the loosely agglomerated form with very fine particles with about 50nm average size.

Higher density and lower porosity of the stack separator are the key parameters for getting good properties, such as mechanical and electrochemical. The microstructures of the polished specimens were observed by FESEM. Fig. 2(b) shows surface of STS+ TiC_xN_y specimens.

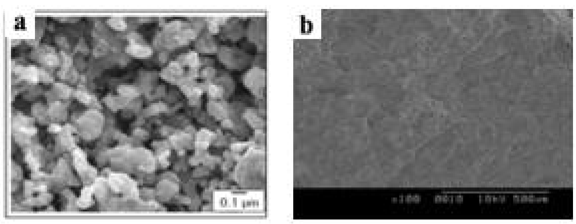

Fig. 2 FESEM morphology (a: developed TiC_xN_y powder, b: STS+5%TiN_xN_y)

The stack separator should have good bending strength in order to provide good mechanical support to fuel cell system. Fig. 3 summarizes the bending strength data of the sintered specimens. As it was expected the finer microstructure of the titanium carbonitride powders helps to increase the mechanical properties of the composites. The pure STS sintered specimen demonstrates the lowest biaxial strength.

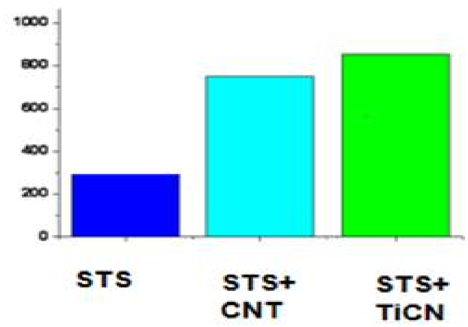

Fig. 3 Biaxial strength of the specimens

During the fuel cell operation, the stack separator interacts with oxidizer in one side. This interaction makes another requirement for stack separator. The stack separator should have higher corrosion resistance in order to provide long-time operation of fuel cell. Fig. 4 illustrates the corrosion resistance test results of the specimens. The specimen obtained from mixture of STS and TiC_xN_y shows lower current density in active region, which means that TiC_xN_y is more stable. The addition of TiC_xN_y affects the polarization effect of the composites.

Generally, STS plate and sintered STS plate demonstrate almost no change in corrosion current density, which means that these materials have passivity behavior in active region. However, the increase of corrosion current density of the sample prepared by mixing STS and TiC_xN_y is the smallest. From these results it can be concluded that STS+ TiC_xN_y is more noble material with high corrosion resistance property, and this property doubtless allows the use of this material for making stack separator.

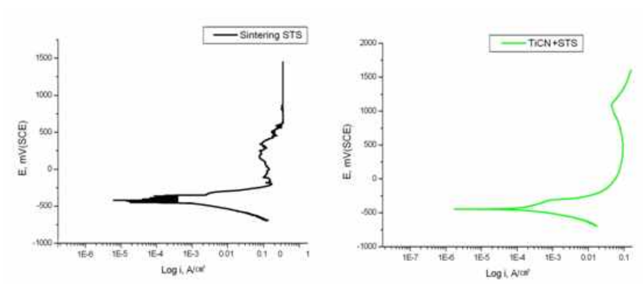

Fig. 4 Potentiodynamic diagrams of STS and STS + TiC_xN_y composite

Conclusion

The stack separator used in fuel cells is one of the most important components of fuel cells. As separator is exposed to both the oxidizing and reducing side of the cell at high temperatures, it must be extremely stable at high temperatures. Nano-sized TiC_xN_y played an important role in the mechanical properties, such as bending strength of the composites.

From the potentiodynamic diagrams it can be observed that the composite of STS+TiC_xN_y has more noble properties than STS sintered one such as high corrosion resistance.

References

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