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Thermodynamics and Kinetics of Immersion Behavior of IC221M Alloy as a Separator in Molten Carbonate Fuel Cell

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1- Introduction

The direct contact between separator plates and the molten salt, resulting in the corrosion of these plates in wet-seal areas is the most important life limiting factor of molten carbonate fuel cells. Ni based superalloys have been introduced as the material with desired resistance in this application but they are not suitable from the economical point.

IC221M is a nickel-aluminide intermetallic (Ni_3Al) base alloy, with characteristics similar to superalloys. Because of the high content of γ', the mechanical properties of this intermetallic will decrease at temperatures higher than 800 °C.

According to IC221M applications, there is a surface oxidation on the alloy, therefore most researches have tried to optimize the performance in oxidizing conditions and reduce the oxidation rate of the alloy. However, the compositions obtained from the oxidation above the surface, are the most resistant compounds in molten carbonate. Therefore, controlled surface oxidation of IC221M can be proposed to establish a protection in molten carbonate environment. In this research, the effect of molten carbonate on the behavior of IC221M has been investigated.

2- Experimental

The behavior of IC221M alloy was investigated in molten carbonate with eutectic composition ($43Li_2CO_3$-$57Na_2CO_3$) according to working conditions in molten carbonate fuel cell. The working temperature considering the conditions in MCFCs, was selected as 600, 650 and 700°C to investigate.

To determine the scale and the rate of corrosion, immersion time varied from 0.5 to 125 hours, isothermally. Samples were cooled and weighted after the end of the immersion. Microstructure analysis was performed using SEM and also XRD was used for phase identification of samples and molten salt after immersion test.

3- Results and Discussion

After 125 hours immersion at 700°C, there was surface products, regularly formed on all faces of the samples with uniform shape and also the base metal was consumed uniformly on all faces too.

According to Fig. 1 sectional back-scattered images from one of the samples shows that the microstructure of the surface products mainly formed by two phases (black & white layers) which repeated periodically throughout the thickness of products; from alloy interface to outer top.

-Immersion time & temperature. The weight of the samples changes versus immersion time and is demonstrated in Fig. 2 (weight changes have been considered for samples together with surface productions). According to this plot, direct influence of temperature on corrosion rate can be observed. Weight gain trend at 700°C indicates the increase in corrosion rate as the immersion time passes.

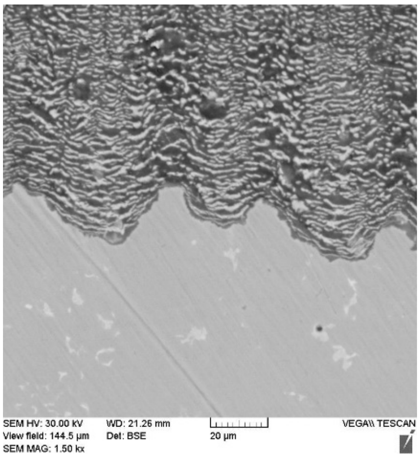

Fig. 1 Sectional SEM image from alloy/surface products interface after 100 h immersion at 650°C.

The microstructure of the surface products consists of black & white layers with same chemical composition for each uni-color layers. Based on this, it can be concluded that IC221M behavior is independent from immersion temperature and as molten salt temperature increases, corrosion rate and products formation will be increase with same type of behavior.

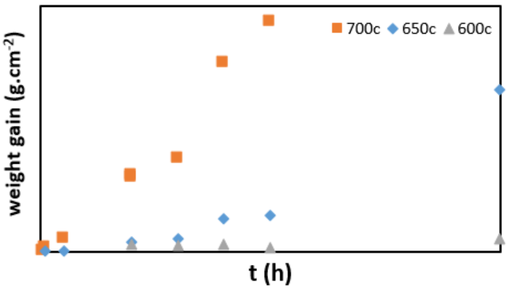

Fig. 2 Weight gain vs. temperature for samples after isotherm immersion test

-process controlling criteria. Absence of any new compound resulting from immersion, indicates that the alloy corrosion process is equivalent with formation of surface products. According to Fig. 3, no composition or compound has been formed (in considerable amount) after immersion on surface production which can be related to a chemical reaction.

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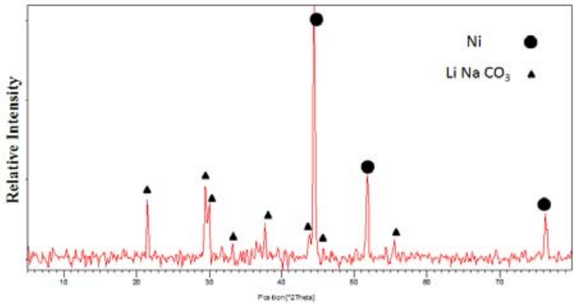

Fig. 3 XRD pattern obtained from surface production after 125 h immersion in 700ºC

Using weight loss data and according to Fig. 4, activation energy can be determined as 423kj/mol. Considering the previous researches this amount shows that the corrosion process is controlled by aluminum diffusion.

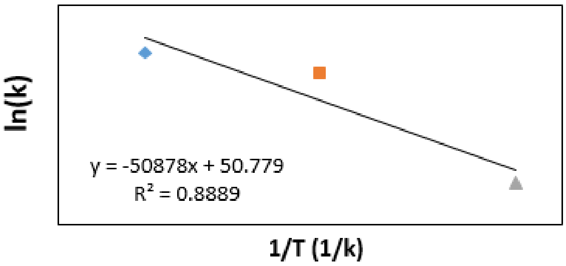

Fig. 4 ln(k) vs. 1/T obtained from weight loss data in 3 different temperature

Considering there is a few reactions which can be accrued during the process, XRD patterns rejected the possibility of formation of compounds such as Al_2O_3 or $NiAl_2O_4$ in considerable amounts. Therefore, despite calculating the activation energy assuming the process is controlled by reaction, no reaction affected the process; although there might be small amount of products resulted by reactions but they cannot have any major contribution to the progress of the process.

4- Conclusions

Immersion test at 600, 650 and 700ºC indicates the high corrosion rate (especially at 700ºC) and weight gain versus immersion time. So the as cast IC221M alloy cannot be used as a separator plate in MCFC wet-seal area.

After immersion, surface products formed regularly on all faces of the samples with a uniform layer microstructure consisting of a black & a white layer repeated throughout the thickness.

According to samples corrosion rate and weight gain, immersion temperature has a major effect on surface products formation while immersion time has a uniform and stable influence on the process.

The activation energy was calculated as 423kj/mol for the process which indicates that the process is controlled by aluminum diffusion.