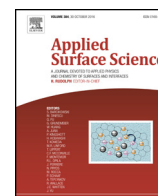




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Full length article

Effect of a nano-sized TiC particle addition on the flow-assisted corrosion resistance of SA 106B carbon steel

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ABSTRACT

Carbon steel with dispersed nano-sized TiC ceramic particles was fabricated by the ex-situ introduction of the particles into the melt, with the flow-assisted corrosion (FAC) resistance then investigated in the presence and absence of TiC nanoparticles using a once-through type of FAC loop test. From the potentiodynamic polarization curves, the current density at any given anodic potential was decreased and the open-circuit potential was increased by the addition of TiC nanoparticles. In addition, when the nano-sized TiC particles were added, the FAC rate was 1.38 times lower than that of carbon steel without TiC nanoparticles, indicating an improvement of the FAC resistance due to the homogeneous distribution of the TiC reinforcing nanoparticles.

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1. Introduction

Carbon steel has been widely used as a pipelines component in the secondary coolant systems of nuclear power plants due to its good formability, weldability, workability, and low cost [1,2]. In such applications, materials are prone to cavitation erosion, flow-assisted corrosion (FAC), intergranular cracking, and low-cycle corrosion fatigue [3–5]. Among these types of damage, FAC during operation often results in large areas of pipe thinning, with the affected pipes eventually rupturing and possibly causing a catastrophic failure of the components. The sudden rupture of the feedwater piping in the Mihama-3 nuclear plant in Japan caused by FAC emphasizes the importance of the reliability and integrity of carbon steel components [6].

In this regard, metal matrix nanocomposites (MMNCs) are among the most attractive materials to improve the reliability and integrity of materials including the strength, toughness and surface properties, from a metallurgical viewpoint [7–13]. However, it is exceptionally difficult to achieve a homogeneous dispersion of ceramic nanoparticles in an iron-based molten metal. Only a few recent studies [14–17] have reported the fabrication of cast steel dispersed with nano-sized ceramic particles using a liquid metal casting process. However, they focused on changes in the microstructure and mechanical properties caused by the distribu-

tion of reinforced ceramic nanoparticles. In the present work, on the basis of the present author's previous investigations [16,17], the effects of an addition of nano-sized TiC particles on the FAC resistance of SA 106B carbon steel were investigated based on a once-through loop-type FAC experiment.

2. Experimental methods

The experimental work was carried out with as-cast SA106 Grade B (UNS No. K03006) carbon steel and a modified type of carbon steel after treatment of the melt with nano-sized TiC particles of 0.1 wt.%. The details of the procedure used to modify the carbon steel through the direct introduction of mechanically activated TiC nanoparticles into the melt and the chemical composition of the carbon steel are described in previous work by the author [16,17]. In brief, after melting the starting materials, reinforcing dispersoid powders packed in a carbon steel canister were externally introduced into the melt in a vacuum induction furnace. Reinforcing dispersoid powders including nano-sized TiC particles of 0.1 wt.% were prepared using a mechanical activation process together with Fe and Ni metal powders using a home-made very high-speed planetary ball mill apparatus in an argon atmosphere. The distribution characteristics of TiC nanoparticles in the cast matrix was clarified by using a high-resolution transmission electron microscopy (HRTEM, JEOL JEM-2100F) including a selected area electron diffraction pattern (SADP).

In order to measure the FAC rate, a once-through type of FAC loop was designed and realized, as illustrated in Figs. 1 and 2,

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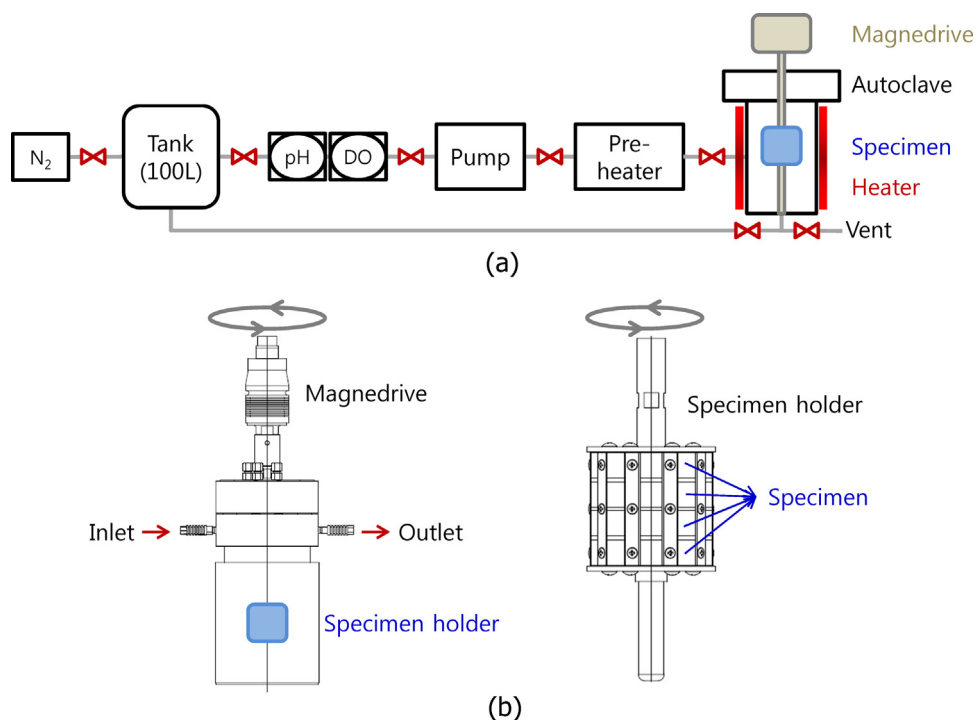


Fig. 1. (a) Schematic diagram of the once-through type FAC test loop and (b) details of the autoclave and FAC specimen holder used in this study.

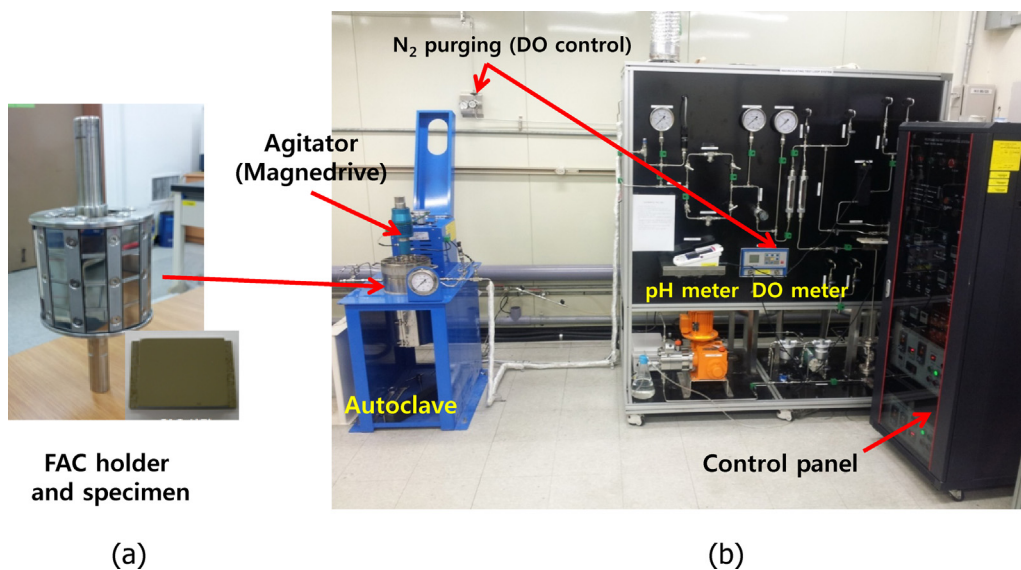


Fig. 2. Actual images of (a) the FAC test holder and specimen and (b) the once-through type FAC test loop.

respectively. An autoclave consisting of type 316 stainless steel with a volume of 1 gallon (3.78L) was used for the maintenance of the FAC test environment, and the flow rate was controlled by rotating the specimen holder, which in this case was connected to a MagneDrive agitator, as shown in Fig. 1(b). The water chemistry during the FAC test was based on the conventional pressurized-water-reactor (PWR) secondary coolant conditions. Deaerated deionized water with uniform pH and dissolved oxygen concentration (DO) values was used as the FAC test solution. The DO value could be controlled at the target levels by purging with an inert nitrogen gas. Simultaneously, the pH value was controlled by the addition of lithium hydroxide (LiOH). Conditioned water was

then fed to the test autoclave through a preheater. The DO and pH values of the water in the reservoir tank were measured at room temperature using a batch-type DO and pH meter. The flow velocity was controlled through the RPM of the MagneDrive. The FAC tests were carried out for time periods of up to 28 weeks using the same three specimens. The weight loss of the specimens was measured once a week and the effluent water was cleaned concurrently in an ion exchange resin column to remove impurities, with the effluent water then fed back into the reservoir tank. Details pertaining to the FAC test solution are summarized in Table 1. The morphological characterization of the specimen was done using scanning

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