§26. Measurement of Mechanical Strength of the First Wall Coating by Means of Laser-shock Method

Satou, M. (Hachinohe Inst. Tech.),
Nagasaka, T.

Vanadium alloys are considered as candidate structural materials for the self-cooled blanket of an advanced fusion reactor, because of their high–heat-load capability, low induced radioactivity and compatibility with liquid lithium as a coolant. For application as a self-cooled blanket design with liquid lithium, the remaining issues are to reduce the magnetohydrodynamic (MHD) pressure drop and to improve the chemical compatibility with lithium. One solution is to coat the alloy with a ceramic material that has high electrical resistivity and better chemical compatibility with lithium. Previous assessment of insulating properties and chemical compatibility at elevated temperatures resulted in the selection of yttria (Y_2O_3) as a prime candidate for the coating ceramic. It is necessary to evaluate the adhesive strength between the ceramic and vanadium alloy, because the integrity of the interface is essential to maintain the performance of the coating. In this study, a laser shock spallation method was utilized to measure the adhesive strength between yttria and vanadium alloys.

Selected V-4Cr-4Ti-Y-Si-Al alloys were used as substrate materials. Yttria was coated at a thickness of approximately 100 μm on the alloys by vacuum plasma-spray (VPS). The adhesive strength between the yttria coating and vanadium alloys was measured by the laser shock spallation method[1),2)]. The Nd:YAG (neodymium-doped yttrium aluminum garnet) laser was used. The laser was focused to a 3 mm diameter spot on the substrate using a convex lens. In order to apply an efficient shock wave to the substrate, a 50 μm thick water glass layer was applied to the back of the substrate, where the Nd:YAG laser was irradiated. A compressive shock wave propagated through the interface between the coating and the substrate, and was then reflected as a tensile wave from the free surface. The tensile wave would exfoliate the coating if the amplitude of the wave created sufficient stress that was higher than the adhesive strength of the interface. The minimum laser energy that resulted in exfoliation of the coating from the interface was defined as the critical energy. Nd:YAG laser shots with various energies up to 1.6 J were focused at different spots on the substrate. The adhesive strength corresponds to the tensile stress applied at the critical laser energy. The tensile stress between the coating and substrate was calculated by the displacement velocity of the free surface measured using an optical interferometer with a diode pumped solid state (DPSS) laser.

To prevent crack formation in the coating layer by using thinner coating specimens, the 100 μm thick yttrium oxide layer was thinned to 30 μm by polishing. Fig. 1 shows the exfoliation behavior of the 30 μm thick specimen. Detailed Scanning electron microscope (SEM) observation of the cross section after laser shot indicated that laser energy of 77 mJ or less did not create interface cracks, but more than 89 mJ resulted in the initiation of cracks, as shown in Fig. 2. The typical adhesive strength of an yttrium oxide layer on vanadium alloy was evaluated to be approximately 400 MPa.[3)] Several modes of the exfoliation behavior were categorized after cross-sectional SEM observations. Coating specimens were thinned in an attempt to prevent crack formation in the coating layer for accurate evaluation of the adhesive strength of the interface between the coating and alloy substrate.

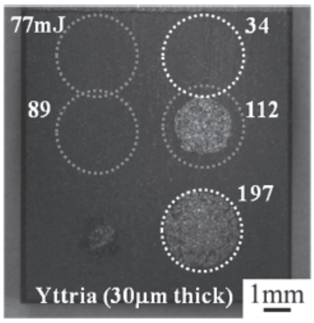

Fig. 1. Surface view of the coating layer on V-4Cr-4Ti-0.1Y-0.1Si alloy after laser shots of various energy.

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2) Satou, M., Akamatsu, H., Hasegawa, A.: Shock Compression of Condensed Matter-2009,CP1195,1131.
3) Satou, M. Akamatsu, H., Nagasaka, T., Hasegawa, A. : MRS Proceedings, 1298, (2011) mrsf10-1298-q06-07 doi:10.1557/opl.2011.563.

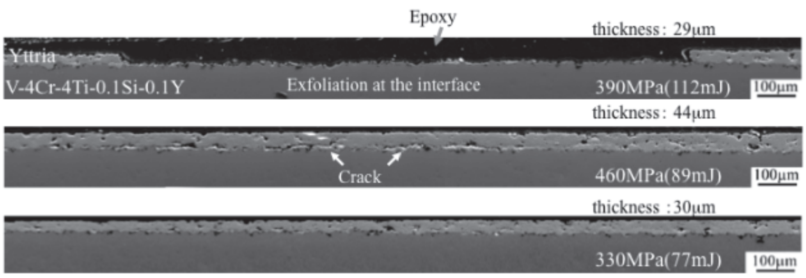

Fig. 2. Cross sectional SEM images of the coating layer on V-4Cr-4Ti-0.1Y-0.1Si alloy after laser shots of various energies.