Mitigating Stress Corrosion Cracking and Irradiation Defects in ODS Austenitic Alloys by Laser Shock Peening

Xueliang Yan,* Yongfeng Lu,† Michael Nastasi*, Bai Cui*

*Department of Mechanical & Materials Engineering, University of Nebraska-Lincoln, Lincoln, NE 68588, bcui3@unl.edu
†Department of Electrical Engineering, University of Nebraska-Lincoln, Lincoln, NE 68588

INTRODUCTION

Oxide-dispersion-strengthened (ODS) austenitic alloys are promising candidate materials for generation-IV nuclear energy systems, such as very-high-temperature reactor (VHTR). At elevated temperatures, the mechanical strength and creep resistance of ODS austenitic alloys are much higher than the conventional austenitic alloys, due to to the homogeneously dispersed nanoscale oxide particles in the matrix, who can impede the motion of dislocations and reduce grain coarsening. However, a concern of stress corrosion cracking (SCC) is raised for the potential applications of ODS austenitic alloys in high-temperature water coolant environments, because its austenitic matrix is susceptible to SCC.[1] Also, there is still a gap between the irradiation resistance of the current ODS austenitic alloys and the requirements of the nuclear energy systems.

Laser shock peening (LSP) is a novel surface engineering process to improve the fatigue and wear resistance of metallic materials. The LSP process utilizes nanosecond laser pulses to irradiate the metal surface to form a plasma, whose expansion generates shock waves that induce significant compressive residual stresses in the materials. In this study, it was demonstrated that LSP can be used to mitigate SCC and irradiation defects of ODS austenitic alloys.

RESULTS

The microstructures near the surface (~50 µm) of LSP-treated ODS 304 alloys were characterized by transmission electron microscopy (TEM), as shown in Fig.1 (a) and (b). A much higher density of dislocations, stacking faults, and deformation twins were observed after LSP compared to the untreated samples. The microstructural changes indicate that significant plastic deformation occurred by the interaction of laser-driven shock waves and the austenitic matrix.

The SCC behavior of LSP treated alloys was examined under a constant load of 177 MPa in a 42% $MgCl_2$ aqueous solution at 143 °C. As shown in Fig.1 (c), it can be seen that SCC had been initiated and propagated along the grain boundaries in the untreated 304 steels after 72 h. However, in the LSP-treated 304 steels, no SCC was observed under the same condition. The improvement of SCC resistance after LSP treatment is attributed to the formation of a surface layer with significant compressive residual stress and plastic deformation. Compressive residual stress generated by LSP can counteract the applied tensile stress in the near surface, which may increase the critical stress for crack propagation by reducing the stress intensity factors.

The irradiation behavior of LSP-treated ODS 304 steels was investigated by *in situ* TEM irradiation experiments with 1 MeV Kr ions at Argonne National Laboratory. A large number of irradiation defect clusters was generated in ODS 304 steels during Kr^+ irradiation. The number density of irradiation defect clusters in the regions close to dislocation lines or deformation twin boundaries are found to much lower than other regions. This phenomenon can be explained by that the dislocations and twin boundaries induced by LSP serve as effective sinks to annihilate the irradiation defects. Consequently, the irradiation resistance is improved as the irradiation defects in LSP-treated ODS 304 steels are much less than that in untreated ones. These findings have important implications for the role of LSP on the lifetime extension of ODS austenitic alloy components in nuclear reactor environments.

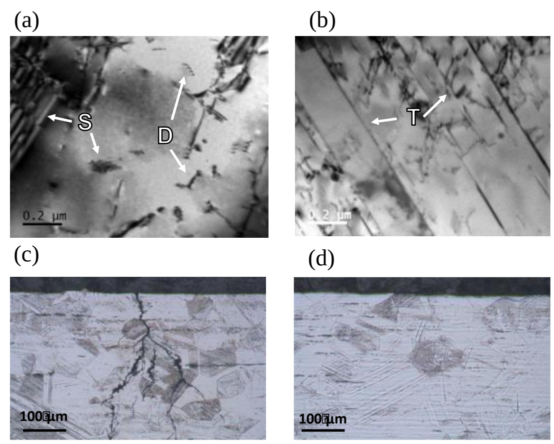

Fig. 1. (a)-(b) TEM images of near-surface microstructures of ODS 304 steels after LSP. S: stacking fault; D: dislocation; T: deformation twin. (c)-(d) Optical micrograph of the cross-section microstructures after SCC test of 72 hours: c) untreated 304 steels; d) LSP-treated 304 steels.

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REFERENCES

1. X. Yan, et al. "Chloride-induced stress corrosion cracking of oxide-dispersion-strengthened austenitic steels" *Corrosion*, in press.