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Effect of laser surface hardening on the hydrogen embrittlement of AISI 420: Martensitic stainless steel

B. Mahmoudi [a,*], M.J. Torkamany [b], A.R. Sabour Aghdam [a], J. Sabbaghzadeh [b]

[a] Department of Materials Engineering, Tarbiat Modares University, Tehran, Iran
[b] Iranian National Centre for Laser Science and Technology, PO Box 14665-576, Tehran, Iran

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ABSTRACT

The susceptibility of stress corrosion cracking (SCC) of AISI 420 which was surface transformed hardened by a pulsed Nd:YAG laser, was investigated in 5% sodium chloride + 0.5% acetic acid solution by the U-Bend method, in the range of pH value from 3.5 to 6, in the absence and presence of 1 ppm thiosulphate ion, at 25 and 60 °C. The results showed that the laser-treated areas are more susceptible to SCC than the base metal. Hydrogen embrittlement (HE) is the main cause of crack propagating, mostly effective on the grain boundaries and the interface between carbide particles and second phases; tempered martensite or ferrite.

1. Introduction

Cavitation erosion is a common cause of failure in machineries such as hydro-turbines, ship propellers, pumps, valves and diesel engines [1,2]. The local pressure variations within the liquid lead to the nucleation of cavities and their subsequent collapse generates high-pressure shock waves and microjets which cause erosion of the material. Martensitic stainless steels offer excellent cavitation erosion resistance followed by austenitic and ferritic stainless steels [3]. However, the occurrence of severe erosion has increased in recent years due to higher operational pressures and speeds of hydraulic systems required to cope with increasing energy requirements. The results of previous studies proved that laser-based transformation hardening was an effective and feasible method to increase cavitation erosion resistance in these kind of conditions [4–6]. In some cases like hydro-turbine blades, the local laser-treated areas are under high-tension pressure which originates from high rotating speed or pumps which operate in diverse environments in different pH values and tension stresses. After laser surface hardening, the two different phases, the ferrite and the martensite, with different thermal and mechanical properties, are produced adjacent to each other. Considering high-tension stress at the treated area, the SCC would occur especially in the boundary between treated and untreated regions.

There have been various studies until now in which the SCC mechanism of martensitic stainless steels has been investigated. Adsorption-induced cleavages, atomic surface mobility, film ruptures, stress-accelerated dissolutions, film-induced cleavages, and tunnel pitting are prominent mechanisms which have been proposed up to now [7]. However, scientists mostly believe that hydrogen induces cracks by concentrating in carbide precipitations, reducing plasticity and consequently embrittling them [7]. Under the action of an electrolyte, pits appear on a metal surface, at the apices, of which the nucleation of corrosion cracks is facilitated due to the production of stress concentration. Besides the increase in the stress concentration at the apex of a pit, an essential role in the nucleation of cracks is played by the hydration and embrittlement of the metal in the zone adjacent to the apex. Therefore, the resistance of substrate against the embrittling action of hydrogen may affect the mechanism of the pit-to-crack transition and crack growth markedly [8].

HE of diverse materials or different microstructures of a metal can be compared with the term of hydrogen permeability. The hydrogen permeability is the combination of diffusivity and solubility of hydrogen into the materials [9]. The metallurgical structure and composition influence the solubility and diffusivity of hydrogen into the steels. For instance, a ferritic base-centered cubic (bcc) structure enables a high diffusion rate and a low solubility due to its open lattice structure. In contrast, the austenitic face-centered cubic (fcc) structure gives a lower diffusion rate and a higher solubility due to its close-packed lattice. At room temperature, D in austenitic stainless steel is about 10^{-10} cm^2/s compared to 10^{-5} cm^2/s for pure iron [9]. On the other hand, the solubility in the austenitic structure is much greater than in the ferritic. As a consequence, regarding the effect of both solubility and diffusivity factors, austenitic structure has less permeability compared to ferritic one. Solubility, diffusivity and permeability are strong functions of temperature and follow empirical Arrhenius type equation and by increasing the temperature the absorption

* Corresponding author. Tel./fax: +98 711 6281392.
E-mail address: b.mahmoudi@modares.ac.ir (B. Mahmoudi).

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