INFLUENCE OF MICROSTRUCTURAL MODIFICATION ON THE CORROSION RESISTANCE OF COMMERCIALLY PURE NICKEL NP1 AFTER ELECTROPULSE TREATMENT

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Abstract

Commercially pure nickel NP1 is widely used in corrosive environments because of its excellent chemical stability. Nevertheless, optimization of its corrosion resistance through microstructural engineering remains an important scientific challenge. The present study investigates the influence of cryogenic rolling followed by electropulse treatment on the corrosion behaviour of NP1 nickel. The relationship between structural evolution and corrosion resistance was evaluated using microstructural observations, microhardness measurements, and corrosion testing. The obtained results demonstrate that electropulse treatment promotes structural homogenization and improves corrosion resistance through the formation of a refined and stable microstructure.

Keywords: Nickel NP1, Corrosion resistance, Electropulse treatment, Cryogenic rolling, Microstructure, Grain refinement.

1. Introduction

Nickel is one of the most corrosion-resistant engineering metals and is widely used in the chemical, petrochemical, energy, marine, and aerospace industries. Its excellent resistance to acids, alkalis, and atmospheric corrosion makes it an important structural material for aggressive service environments.

Corrosion resistance is determined not only by the chemical composition of a material but also by its microstructure. Grain size, grain-boundary distribution, dislocation density, residual stresses, and crystallographic texture strongly influence electrochemical behaviour. Structural refinement may either improve or deteriorate corrosion resistance depending on the balance between passive film formation and defect density.

Cryogenic rolling introduces a large number of deformation defects and produces an ultrafine-grained structure, whereas electropulse treatment accelerates recovery and recrystallization processes within a very short processing time. Such combined processing offers a promising route for controlling both mechanical and corrosion properties without conventional heat treatment.

The objective of this work is to evaluate the influence of electropulse treatment on the corrosion resistance of cryogenically rolled commercially pure NP1 nickel and to establish the relationship between structural evolution and electrochemical performance.

2. Materials and Methods

2.1 Material

Commercially pure nickel NP1 with a purity of approximately 99.9 wt.% was used in this investigation. Prior to deformation, all specimens were annealed at **600 °C for 2 h** to obtain a homogeneous initial microstructure. The chemical composition of the material complied with the requirements of GOST 492–2006.

2.2 Cryogenic Rolling

Cryogenic rolling was carried out using a laboratory six-high rolling mill. The specimens were immersed in liquid nitrogen during deformation in order to suppress dynamic recovery and maximize defect accumulation. The rolling speed was maintained below **100 mm min^{-1}**, while the reduction per pass did not exceed **5%**. The total reduction reached **70%**, producing a heavily deformed microstructure with a high density of lattice defects.

2.3 Electropulse Treatment

Electropulse treatment (EPT) was performed on rolled specimens measuring **0.4 × 4 × 20 mm**. The electric current was applied through copper electrodes, and the active treatment zone had a length of **10 mm**. Pulse duration was approximately **100 μs**.

The integral current density was calculated from the electrical pulse recorded using a Rogowski coil connected to a digital oscilloscope. The processing temperature was estimated using the Joule–Lenz relationship because direct temperature measurements were impossible during such short pulses.

2.4 Corrosion Testing

Corrosion resistance was evaluated after cryogenic rolling and electropulse treatment. The corrosion behaviour of the processed specimens was compared with that of the initial material to determine the influence of structural modification. The corrosion results were analyzed together with the observed changes in microstructure and microhardness in order to establish the relationship between structural evolution and corrosion performance.

2.5 Microstructural Characterization

Microstructural observations were carried out using Electron Backscatter Diffraction (EBSD). Grain morphology, grain-boundary character, recrystallized fraction, and crystallographic orientation were analyzed before and after electropulse treatment. The obtained structural information was correlated with the corrosion behaviour of NP1 nickel.

3. Results and Discussion

3.1 Structural Evolution

Cryogenic rolling introduced severe plastic deformation into NP1 nickel, resulting in elongated grains and a high density of deformation defects. These defects served as stored deformation energy, which later promoted rapid recovery and recrystallization during electropulse treatment.

After EPT, the microstructure became more homogeneous owing to the formation of new recrystallized grains. Grain refinement reduced structural heterogeneity and internal stresses throughout the material.

3.2 Effect on Corrosion Resistance

The corrosion experiments demonstrated that structural modification significantly affected the corrosion behaviour of commercially pure nickel.

Cryogenically rolled samples exhibited higher stored strain energy and a greater density of lattice defects. After electropulse treatment, recovery and recrystallization reduced these defects, leading to the formation of a more uniform passive surface layer.

Consequently, the corrosion resistance of NP1 nickel improved after combined cryogenic rolling and electropulse treatment. The enhanced corrosion performance is mainly associated with grain refinement, reduction of residual stresses, and structural homogenization.

3.3 Relationship Between Microstructure and Corrosion

The present investigation confirms that corrosion resistance is closely related to the microstructural state of the material. Fine recrystallized grains facilitate the formation of a stable oxide film, whereas excessive deformation defects may act as preferential corrosion initiation sites.

Electropulse treatment effectively optimized the balance between defect density and grain refinement, resulting in improved corrosion behaviour without prolonged thermal exposure.

4. Conclusions

The present study investigated the influence of cryogenic rolling followed by electropulse treatment on the microstructure and corrosion resistance of commercially pure NP1 nickel.

Based on the obtained experimental results, the following conclusions can be drawn:

Cryogenic rolling introduced a high density of deformation defects and produced a refined deformed microstructure, leading to a significant increase in microhardness.

Electropulse treatment promoted recovery and recrystallization processes, resulting in the formation of a more homogeneous grain structure and partial relaxation of internal stresses.

EBSD analysis confirmed the transformation of elongated deformation grains into finer recrystallized grains after electropulse treatment, indicating efficient microstructural modification.

Structural homogenization after electropulse treatment contributed to the formation of a more stable passive surface layer on NP1 nickel.

Corrosion tests demonstrated improved corrosion resistance after the combined application of cryogenic rolling and electropulse treatment. The improvement is associated with grain refinement, reduction of structural heterogeneity, and optimization of grain-boundary characteristics.

The obtained results confirm that electropulse treatment represents an effective alternative to conventional heat treatment for tailoring the structural, mechanical, and corrosion properties of commercially pure nickel.

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