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Improvement of low-cycle fatigue life of austenitic stainless steel by multiple high-density pulsed electric currents

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ABSTRACT

This study evaluated the low-cycle fatigue (LCF) life of type 316 austenitic stainless steel to determine the effect of multiple high-density pulsed electric currents (HDPECs). Fatigue properties were analyzed with the fatigue crack growth (FCG) and LCF tests by considering different conditions of multiple HDPECs and its application. The HDPEC densities of 100, 150 and 200 A/mm^2 with application numbers from 1 to 17 times were used. The LCF results were assessed by using fatigue models, and the effectiveness of the application methods was examined. Under the HDPEC density of 200 A/mm^2, increasing the number of HDPECs during the period of crack propagation is the best way for delaying FCG. Multiple applications of HDPEC caused a decrease in the length and an increase in the depth of striations in the specimen's fatigue fracture surface, and the degree of ductility was increased thereby leading to the delay in FCG. The proposed conditions pave the way toward improving the LCF life of the material.

1. Introduction

Type 316 austenitic stainless steel is one of the most widely used structural steels. It has been used in the manufacture of mechanical components of power plants, chemical facilities, and marine structures owing to its good formability, weldability, and anti-corrosion characteristics. In these engineering applications, the mechanical components are frequently subjected to repetitive high strain amplitudes, which can lead to failure under a low number of fatigue cycles. To evaluate mechanical properties of materials under such strains, the low-cycle fatigue (LCF) approach is more appropriate as opposed to the high-cycle fatigue (HCF) approach. Consequently, the LCF tests are a well-known method for assessing the reliability of a material [1,2].

Many researchers have attempted to improve the fatigue properties of materials in the LCF and HCF regimes. For example, the fatigue strength of carburized austenitic stainless steel was improved owing to the discontinuity of crack initiation. The carburized layer formed on the surface leads to small surface cracks before initiating large ductile cracks in the base material, and gives additional fatigue lives regardless of stress level and external factors such as air and corrosive environment [3]. Additive-manufactured austenitic stainless steel has a higher fatigue limit than rolled steel owing to grain refinement and reduction of ductility [4]. The improvement of surface hardness and fatigue strength in nitrided austenitic stainless steel was achieved by the treatment of fine particle peening [5]. As such, various modification techniques have mostly been developed through mechanical and chemical treatments [6].

In the past few decades, the application of high-density pulsed electric current (HDPEC) has been considered an accessible method for improving the fatigue life of metals [7–13]. So far, it has been reported to be a promising treatment for metals such as stainless steel [7,8], high-strength steel [9], polycrystalline copper [10], drawing quality steel [11] and aluminum alloy [12]. The electric current leads to changes in the dislocation motion, grain size and phase structure [8,13–15] owing to the induced electron wind force (EWF) and Joule heating [16]. Although underlying mechanisms have been elucidated, improvements in the method of application of electric current treatment and its impact on fatigue properties have not yet been sufficiently addressed. Methodological assessments are needed to determine how this treatment can be applied efficiently and how much fatigue life can be improved under given fatigue circumstances.

In this study, a series of LCF tests was conducted to investigate the effects of multiple applications of HDPEC. First, fatigue crack growth (FCG) tests were performed to determine the appropriate density of the electric current. Then, strain-controlled LCF tests were conducted to evaluate the degree of change in the LCF life with the number of HDPECs and their manner of application. The LCF properties were analyzed by

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