® INDUSTRIAL FASTENERS INSTITUTE

Hydrogen embrittlement characteristics of two tempered martensitic steel alloys for high-strength bolting

Brahimi, S V; Sriraman, K R; Yue, S

Proceedings of the Institution of Mechanical Engineers 231(17):3214
2017-09-01 (first published April 2016), 09544062

The following page contains the abstract of a journal article based on long-term research on the susceptibility to hydrogen embrittlement of martensitic steels used for manufacturing fasteners being conducted at McGill University's Hydrogen Embrittlement Facility (MHEF). The lead author, Salim Brahimi, is co-founder of the MHEF and the current Director of Engineering Technology of the Industrial Fasteners Institute (IFI). The research presented is this paper was funded in part by the IFI.

The complete article citation is given below and may be purchased at:
http://journals.sagepub.com/doi/pdf/10.1177/0954406216642476

> Brahimi SV, Sriraman KR, Yue S. Hydrogen embrittlement characteristics of two tempered martensitic steel alloys for high-strength bolting. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2016 Apr 6:0954406216642476.

Research on Fastener Hydrogen Embrittlement at McGill University in Montreal, Canada began in 2006 as a collaborative effort, co-sponsored by industry and the Government of Canada through the Natural Sciences and Engineering Research Council (NSERC). Industrial partnership was led by the Industrial Fasteners Institute (IFI) and the Canadian Fasteners Institute (CFI), Boeing, Infasco, Nucor Fasteners, Research Council on Structural Connections (RCSC), and ASTM Committee F16.96 on Bolting Technology. The ongoing research follows two distinct tracks: (i) fastener materials susceptibility to HE, and (ii) interactions of fastener materials with coatings and coating processes.

For more information on McGill University's Hydrogen Embrittlement Facility (MHEF), see http://mhef.lab.mcgill.ca.

Sep. 2017

Review Article

Journal of MECHANICAL ENGINEERING SCIENCE

Proc IMechE Part C: J Mechanical Engineering Science
0(0) 1–14

DOI: 10.1177/0954406216642476
pic.sagepub.com

Hydrogen embrittlement characteristics of two tempered martensitic steel alloys for high-strength bolting

SV Brahimi[1,2], KR Sriraman[1] and S Yue[1]

Abstract

Hydrogen embrittlement threshold curves were derived for two quenched and tempered steel grades, AISI 4135 and AISI 4340, at varying hardness ranging from 33 to 54 HRC. For each material, hydrogen was introduced (i) by zinc electroplating as a worst case condition for internal hydrogen embrittlement and (ii) by imposing cathodic potential of −1.2 V as a worst case condition for environmental hydrogen embrittlement. Overall, AISI 4135 exhibited lower thresholds than AISI 4340, making it the more susceptible of the two alloys. The findings demonstrate although hardness and/or strength have a first-order effect on hydrogen embrittlement susceptibility, difference in chemistry leading to differences microstructural characteristics must also be considered. Below hardness of 39 HRC, both alloys were not susceptible to internal hydrogen embrittlement, a finding that is consistent with common industry practice and fastener electroplating standards that do not mandate baking of electroplated fasteners with specified hardness below 39 HRC.

Keywords

High-strength fasteners, high-strength bolting, hydrogen embrittlement threshold, hydrogen embrittlement susceptibility, tempered martensite, zinc electroplating, cathodic charging, internal hydrogen embrittlement, environmental hydrogen embrittlement

Date received: 27 May 2015; accepted: 24 February 2016

Introduction

High strength and ultrahigh strength threaded mechanical fasteners are broadly characterised by tensile strengths ranging from 1000 to 2000 MPa. They are often used in critical components, typically comprising load bearing bolted joints in aircraft structures, ships, ground vehicles, bridges, tunnels and buildings. High strength threaded steel fasteners are also susceptible to hydrogen embrittlement (HE). Important considerations in the prevention of HE are the selection and heat treatment of materials used to manufacture threaded fasteners. Typically, fasteners specifications only place broad restrictions on material selection but do not mandate the selection of a particular grade of steel.

This paper is part of a larger body of work aimed at better defining the relationship between chemical composition, microstructural characteristics and HE susceptibility of high-strength steel used for manufacturing mechanical fasteners. It is generally understood that strength and/or hardness have a first-order effect on HE susceptibility in high-strength steel. In this study, observations made on two alloys illustrate differences in relative susceptibility that are dependent on chemistry and heat treatment, and ultimately on microstructure. The principal investigative technique used is incremental step loading (ISL) based on test method ASTM F1624.[1] In brief, this approach consists of performing a mechanical test on a notched square bar specimen that has either been pre-charged with hydrogen or is cathodically charged during the test under potentiostatic control. The test methodology is designed to measure the HE cracking threshold of the material. Under standardised test conditions, the measured cracking threshold of the specimen is a function of the metallurgical and mechanical properties of the material.

HE threshold

The susceptibility of a material to HE is characterised by its *threshold stress*, $K_{I(HE)}$, which is defined by

[1]Department of Mining & Materials Engineering, McGill University, Montreal, QC, Canada
[2]IBECA Technologies Corp., Montreal, QC, Canada

Corresponding author:
SV Brahimi, IBECA Technologies Corp., 4 Parkside Place, Montreal, QC H3H 1A8, Canada.
Email: salim.brahimi@ibeca.ca