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Hydrogen Embrittlement Susceptibility of Case Hardened Steel Fasteners

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The following pages contain the abstract of a journal article on the susceptibility to hydrogen embrittlement of case hardened steel fasteners. The lead author, John Medcalf, is currently Principal Engineer at Peak Innovations Engineering, Rockford, IL. This paper is based on his Master of Science in Mechanical Engineering thesis at the University of Illinois at Urbana-Champaign. The bulk of experimental work was conducted at McGill University's Hydrogen Embrittlement Facility (MHEF) under the supervision of Salim Brahimi, 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 supported in part by the IFI.

The complete article citation is given below and may be purchased directly from SAE International.

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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.

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Abstract

This work establishes the relationship between core hardness, case hardness, and case depth on susceptibility to hydrogen embrittlement of case hardened steel fasteners. Such fasteners have a high surface hardness in order to create their own threads in a mating hole, and are commonly used to attach bracketry and sheet metal in automotive applications. While case hardened fasteners have been studied previously, there are currently no processing guidelines supported by quantitative data for fastener standards. Through sustained load embrittlement testing techniques, the susceptibility of case hardened steel tapping screws to internal and environmental hydrogen embrittlement is examined. Further characterization of the fastener samples through microhardness testing, microstructure review, and fracture surface examination allows the investigation of susceptibility thresholds. It is shown that core hardness is the primary consideration for susceptibility. However, the fastener surface is prone to failure before the bulk section, up to the case depth, according to the case hardness. The zinc acid electroplating process used on the fasteners in this study appeared not to induce internal hydrogen embrittlement. However, baking durations commonly used for hydrogen embrittlement relief are shown to be ineffective and possibly detrimental.

Introduction

The susceptibility of case hardened fasteners to hydrogen embrittlement is not a new revelation. In 1996, Baggerly studied the failure of a heavy truck wheel bolt [1]. His failure and fracture mechanics analysis demonstrates that in such a high strength application, simply the act of installing a carburized fastener can create cracks in a case hardened surface. Additionally, once these cracks are formed, they create areas where localized corrosion can create an influx of hydrogen. In the bolts studied, this condition then led to fastener failure, with the failed bolts exhibiting a core hardness in the range of HRC 36 to 38 and a case hardness in the range of HRC 42 to 47. However, no conclusions are drawn as to the susceptibility of fasteners in less critical, high stress applications.

McCarthy, Wetzel, and Kloberdanz also studied the effects of hydrogen embrittlement in automotive fasteners with findings published in 1996 [2]. This study was quite comprehensive in scope, attempting to evaluate the effects of material, heat treatment, plating method, bake time, delay before baking, and others on the embrittlement of fasteners. The topic of interest to the current work was the study of case hardened 1022 steel. However, only one condition was studied, with a core hardness specified between HRC 28 and 36 and a case hardness specified as HRC 45 minimum. Three methods of testing were used to detect embrittlement, and to compare their effectiveness: a Chrysler plate test with sustained loading applied using a wedge under the fastener head specified as PS-9500, a General Motors bending test specified as GM-6661P, and a rising step load test. No failures were observed in the 1022 case hardened material, and therefore very few conclusions were drawn about its susceptibility.

As part of the study with McCarthy et al., Lukito and Szklarska-Smialowska evaluated the same materials for hydrogen trapping and permeability at Ohio State University [3]. Through their potentiostatic pulse experiments, they were able to evaluate a rate of hydrogen flux and trapping for the various materials studied. In comparing case hardened 1022 steel with 1022 steel that had been through hardened, it was shown that the case hardening reduced the hydrogen entry flux into the steel. It was therefore inferred that case hardening should reduce the susceptibility of 1022 steel compared to through hardening.

These studies demonstrate a lack of embrittlement susceptibility for the case-hardened condition evaluated and a possible positive effect of the case hardened layer. However, because only one condition was evaluated, minimal conclusions can be drawn as to the overall susceptibility levels of case hardened fasteners. Also, while the Ohio State study used hydrogen charging during slow strain rate embrittlement testing, the McCarthy et al. study did not consider the effects of environmentally induced hydrogen.