

# Fundamentals Of Hydrogen Embrittlement

Fundamentals of Hydrogen Embrittlement  
A New Concept of Hydrogen Embrittlement in Steel  
Gaseous Hydrogen Embrittlement of Materials in Energy Technologies  
Gaseous Hydrogen Embrittlement of Materials in Energy Technologies  
Hydrogen Embrittlement and Stress Corrosion Cracking  
Gaseous Hydrogen Embrittlement of Materials in Energy Technologies  
Hydrogen Embrittlement Inhibition of Hydrogen Embrittlement in High Strength Steels  
Avoidance of Hydrogen Embrittlement of Steel  
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Metals and Alloys The Problem of Hydrogen in Steel Hydrogen Embrittlement Testing Mechanism of Hydrogen Embrittlement and Guidelines for Fatigue Design Hydrogen Embrittlement Theory and Prevention of Hydrogen Damage in Metals and Alloys *Michihiko Nagumo J. G. Morlet Richard P Gangloff Richard P Gangloff Alexander Robert Troiano R P Gangloff Louis Raymond Barbara Ann Heydorn SAE International P. F. Timmins H.H. Johnson J.G. Morlet (A.R. Troiano) Vladimir A. Polyanskiy Robert Walton Buzzard Pasquale Cavaliere A. R. Elsea L Raymond Branko N. Popov*

this book is the second edition of the one originally published in 2016 as the first comprehensive treatment on the fundamentals of hydrogen embrittlement of metallic materials mainly steel the book provides students and researchers engaging in hydrogen problems with a unified view of the subject establishing reliable principles for materials design against hydrogen embrittlement and assessing their performance are recent urgent industrial needs in developing high strength steel for hydrogen energy equipment and weight reducing vehicles the interdisciplinary nature of the subject covering metal physics materials science and mechanics of fracture has disturbed a profound understanding of the problem in this book previous studies are critically reviewed and supplemental descriptions of fundamental ideas are presented when necessary emphasis is placed on experimental facts with particular attention to their implication rather than phenomenological appearance the adopted experimental conditions are also noted since the operating mechanism of hydrogen might differ by material and environment for theories employed assumptions and premises are noted to examine their versatility progress in the past decade in experimental and theoretical tools is remarkable and has nearly unveiled characteristic features of hydrogen embrittlement proposed models have almost covered feasible aspects of the function of hydrogen this second edition has enriched the contents with recent crucial findings chapters on the manifestation of embrittlement in the deterioration of mechanical properties and microscopic features are reorganized and the description is revised for the convenience of readers systematic understanding a new chapter is created for delayed fracture in atmospheric environments as a conclusive subject of critical ideas presented in this book

many modern energy systems are reliant on the production transportation storage and use of gaseous hydrogen the safety durability performance and economic operation of these systems is challenged by operating cycle dependent

degradation by hydrogen of otherwise high performance materials this important two volume work provides a comprehensive and authoritative overview of the latest research into managing hydrogen embrittlement in energy technologies volume 1 is divided into three parts the first of which provides an overview of the hydrogen embrittlement problem in specific technologies including petrochemical refining automotive hydrogen tanks nuclear waste disposal and power systems and h<sub>2</sub> storage and distribution facilities part two then examines modern methods of characterization and analysis of hydrogen damage and part three focuses on the hydrogen degradation of various alloy classes with its distinguished editors and international team of expert contributors volume 1 of gaseous hydrogen embrittlement of materials in energy technologies is an invaluable reference tool for engineers designers materials scientists and solid mechanicians working with safety critical components fabricated from high performance materials required to operate in severe environments based on hydrogen impacted technologies include aerospace petrochemical refining gas transmission power generation and transportation summarises the wealth of recent research on understanding and dealing with the safety durability performance and economic operation of using gaseous hydrogen at high pressure reviews how hydrogen embrittlement affects particular sectors such as the petrochemicals automotive and nuclear industries discusses how hydrogen embrittlement can be characterised and its effects on particular alloy classes

many modern energy systems are reliant on the production transportation storage and use of gaseous hydrogen the safety durability performance and economic operation of these systems is challenged by operating cycle dependent degradation by hydrogen of otherwise high performance materials this important two volume work provides a comprehensive and authoritative overview of the latest research into managing hydrogen embrittlement in energy technologies volume 2 is divided into three parts part one looks at the mechanisms of hydrogen interactions with metals including chapters on the adsorption and trap sensitive diffusion of hydrogen and its impact on deformation and fracture processes part two investigates modern methods of modelling hydrogen damage so as to predict material cracking properties the book ends with suggested future directions in science and engineering to manage the hydrogen embrittlement of high performance metals in energy systems with its distinguished editors and international team of expert contributors volume 2 of gaseous hydrogen embrittlement of materials in energy technologies is an invaluable

reference tool for engineers designers materials scientists and solid mechanics working with safety critical components fabricated from high performance materials required to operate in severe environments based on hydrogen impacted technologies include aerospace petrochemical refining gas transmission power generation and transportation summarises the wealth of recent research on understanding and dealing with the safety durability performance and economic operation of using gaseous hydrogen at high pressure chapters review mechanisms of hydrogen embrittlement including absorption diffusion and trapping of hydrogen in metals analyses ways of modelling hydrogen induced damage and assessing service life

this important two volume book reviews the problem of degradation of metals and other materials exposed to hydrogen the first part of volume one begins by discussing how the problem of gaseous hydrogen embrittlement affects such sectors as the petrochemicals automotive nuclear and other energy industries part two reviews ways of characterising and testing for hydrogen assisted fatigue and fracture a final group of chapters analyse the ways gaseous hydrogen embrittlement affects high performance steels superalloys titanium and aluminium alloys the first part of volume two reviews the mechanism of hydrogen embrittlement including absorption diffusion and trapping of hydrogen in metals part two discusses ways of modelling hydrogen induced damage and assessing service life the final section in the book assesses future trends in research summarises the wealth of recent research on understanding and dealing with the safety durability performance and economic operation of using gaseous hydrogen at high pressure reviews how hydrogen embrittlement affects particular sectors such as the petrochemicals automotive and nuclear industries chapters review mechanisms of hydrogen embrittlement including absorption diffusion and trapping of hydrogen in metals

this book is designed to help metallurgical chemical mechanical and reliability engineers responsible for the safe operation and maintenance of equipment made of steel

the book presents a collection of chapters on the current problems associated with hydrogen damage it discusses the effect of hydrogen on material properties and its interaction with the material microstructure physical features of hydrogen transport in metals and alloys as well as applicable methods of measuring concentration of hydrogen in solid

media

this book provides a complete description of hydrogen technologies from the basic theoretical underpinnings to the different production routes for various applications it summarizes the most recent research findings with respect to theory and the broad array of industrial technologies currently in place as well as those under development with high potential special attention is given to the hydrogen embrittlement mechanisms at room and high temperatures as well as problems related to hydrogen in liquid and high pressure compressed states the author further describes the hydrogen diffusion embrittlement issues related to different types of metallic materials from steel to light alloys to nickel based superalloys

this memorandum introduces the problem of delayed brittle failures associated with hydrogen in steel particularly high strength steel it is intended to help the steel user determine if he has such a problem the effects of hydrogen on the mechanical properties of steel are dealt with and the behavior of material susceptible to delayed brittle failure is described also the effects of such factors as strength level magnitude of applied stress hydrogen content steel composition test temperature and strain rate on hydrogen embrittlement and the susceptibility to hydrogen induced delayed brittle failure are discussed possible sources of hydrogen in steel and the types of tests useful in determining the susceptibility to delayed failure are outlined author

nineteen papers cover internal hydrogen embrittlement testing for relative susceptibility testing for hydrogen pickup during processing mechanical delay time test hydrogen defection methods hydrogen environment embrittlement

hydrogen evolution and permeation are encountered during electroplating corrosion and cathodic protection hydrogen accumulates in areas of high stress and may reach a critical concentration potentially causing fractures and catastrophic damage hydrogen embrittlement theory and prevention of hydrogen damage in metals and alloys explores the theory of hydrogen permeation in metals and alloys hydrogen embrittlement stress corrosion cracking and passivity materials selection as well as electrochemical and non electrochemical methods for prevention of hydrogen induced damage our goal is to help the next generation of engineers and scientists understand the theory of hydrogen embrittlement and

stress corrosion cracking as well as hydrogen damage prevention strategies ii design models for developing hydrogen damage resistant alloys and iii prevent damage of different industrial components due to the presence and localization of hydrogen in metals to accomplish these objectives the book offers case studies of hydrogen permeation hydrogen embrittlement mechanical properties of alloys hydrogen damage control and solved problems with solutions for the topics covered in the book the book is self containing and targets also senior graduate university corrosion engineering courses the senior undergraduate students have the necessary mathematical exposure and ability to follow the subject the book is useful for undergraduate corrosion courses taught in chemical electrochemical mechanical engineering chemistry metallurgy and material science and will serve as references for individual study provides a comprehensive explanation on hydrogen permeation hydrogen embrittlement and hydrogen induced stress corrosion cracking creating difficulties in development of efficient strategies to preventing different types of hydrogen damage in metals and alloys prepares the next generation of materials scientists chemical engineers and mechanical engineers to advance the hydrogen damage prevention strategies to a higher level and to develop advanced alloys resistant to hydrogen embrittlement and hydrogen induced damage discusses hydrogen induced damage and hydrogen embrittlement mechanisms and the electrochemical and non electrochemical prevention strategies as well as design of alloys resistive to hydrogen adsorption and embrittlement includes solved case studies corrosion analysis and solved problems designed to help the reader to understand the fundamental principles from thermodynamics and electrochemical kinetics the chapters in the book are updated with data published in papers and reviews in the last 20 years including the latest research and results

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