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Standard Terminology Relating to Hydrogen Embrittlement Testing[1]

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1. Scope

1.1 This terminology covers the principal terms, abbreviations, and symbols relating to mechanical methods for hydrogen embrittlement testing, which are present in more than one of the standards under the jurisdiction of ASTM Committee F07 on Aerospace and Aircraft. These definitions are published to encourage uniformity of terminology in product specifications.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials
D4848 Terminology Related to Force, Deformation and Related Properties of Textiles
E6 Terminology Relating to Methods of Mechanical Testing
E8 Test Methods for Tension Testing of Metallic Materials
E631 Terminology of Building Constructions
E1823 Terminology Relating to Fatigue and Fracture Testing
F109 Terminology Relating to Surface Imperfections on Ceramics
F1624 Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique
G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]

3. Significance and Use

3.1 The terms used in describing hydrogen embrittlement have precise definitions. The terminology and its proper usage must be completely understood to communicate and transfer information adequately within the field.

3.2 The terms defined in other terminology standards, are respectively identified in parentheses following the definition.

4. Terminology

4.1 *Definitions:*

baking—heating to a temperature, not to exceed 50°F (27.8°C) below the tempering or aging temperature of the metal or alloy, in order to remove hydrogen before embrittlement occurs by the formation of microcracks.

Discussion—No metallurgical changes take place as a result of baking.

brittle—see **brittleness**.

brittleness—the tendency of a material to break at a very low strain, elongation, or deflection, and to exhibit a clean fracture surface with no indications of plastic deformation. **(E631)**

crack—line of fracture without complete separation. **(F109)**

crack strength—the maximum value of the nominal stress that a cracked specimen is capable of sustaining. **(E1823)**

ductile—see **ductility**.

ductility—the ability of a material to deform plastically before fracturing. **(E6)**

embrittle—see **embrittlement**.

embrittlement—the severe loss of ductility or toughness, or both, of a material, usually a metal or alloy. **(G15)**

environmental hydrogen embrittlement (EHE)— hydrogen embrittlement caused by hydrogen introduced into a steel/metallic alloy from an environmental source coupled with stress either residual or externally applied.

Discussion—Produces a clean intergranular fracture and is not reversible. For the subtle differences between EHE and IHE, see Table X1.1.

environmentally assisted cracking (EAC)— see **stress corrosion cracking**.

fracture strength—the normal stress at the beginning of fracture.

gaseous hydrogen embrittlement (GHE)—a distinct form of EHE caused by the presence of external sources of high pressure hydrogen gas; cracking initiates on the outer surface.

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[1] This terminology standard is under the jurisdiction of ASTM Committee F07 on Aerospace and Aircraft and is the direct responsibility of Subcommittee F07.04 on Hydrogen Embrittlement.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

heat treatment—heating and cooling processes that produce metallurgical changes in the metallic alloy which alter the mechanical properties and microstructure of the metal.

hydrogen-assisted stress cracking (HASC)— crack growth as a result of the presence of hydrogen, which can be either IHE or EHE and sometimes is referred to as hydrogen stress cracking (HSC).

hydrogen embrittlement (HE)—a permanent loss of ductility in a metal or alloy caused by absorption of hydrogen in combination with stress, either an externally applied or an internal residual stress.

hydrogen embrittlement relief—see **baking**.

hydrogen-induced stress cracking—see **hydrogen-assisted stress cracking**.

hydrogen stress cracking—see **hydrogen-assisted stress cracking**.

hydrogen susceptibility ratio (Hsr)—the ratio of the threshold for the onset of hydrogen-assisted cracking to the tensile strength of the material.

internal hydrogen embrittlement (IHE)— hydrogen embrittlement caused by absorbed atomic hydrogen into the steel/metallic alloy from an industrial hydrogen emitting process coupled with stress, either residual or externally applied.

Discussion—For the subtle differences between IHE and EHE see Table X1.1.

notched tensile strength (NTS)—the maximum nominal (net section) stress that a notched tensile specimen is capable of sustaining. **(E1823)**

process—a defined event or sequence of events in plating or coating that may include pretreatments and posttreatments.

reaction hydrogen embrittlement (RHE)— irreversible embrittlement caused by the reaction of hydrogen with metal to form a stable hydride.

residual stress—stress in a metal in the absence of external forces.

sharp-notch strength—the maximum nominal (net section) stress that a sharply notched specimen is capable of sustaining. **(E1823)**

strain—deformation of a material caused by the application of an external force. **(D4848)**

strain rate—the rate of relative length deformation with time due to an applied stress. **(C904)**

stress—the resistance to deformation developed within a material subjected to an external force. **(D4848)**

stress concentration factor (k_t)—the ratio of the greatest stress in the region of a notch or other stress concentrator, as determined by the theory of elasticity or by experimental procedures that give equivalent values, to the corresponding nominal stress. **(E1823)**

stress corrosion cracking (SCC)—a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress.

Discussion—This excludes corrosion-reduced sections that fail by fast fracture. It also excludes intercrystalline or transcrystalline corrosion, which can disintegrate an alloy without either applied or residual stress (G15). In essence the process of SCC and EAC are equivalent.

stress–intensity factor, K—the magnitude of the mathematically ideal crack–tip stress field (stress field singularity) for a particular mode in a homogeneous linear–elastic body. **(E1823)**

Discussion—K_I=for a Mode I (opening mode) loading condition that displaces the crack faces in a direction normal to the crack plane.
K_{II}=for a Mode II (sliding mode) loading condition where the crack faces are displaced in shear sliding in the crack plane and in the primary crack propagation direction.
K_{III}=for a Mode III (tearing mode) loading condition where the crack faces are displaced in shear tearing in the crack plane but normal to the primary crack propagation direction.

susceptibility to hydrogen embrittlement— is a material property that is measured by the threshold stress intensity parameter for hydrogen induced stress cracking, K_{Iscc}, K_{IHE} , or K_{EHE}, which is a function of hardness and microstructure.

threshold (th)—a point, separating conditions that will produce a given effect, from conditions that will not produce the effect; the lowest load at which subcritical cracking can be detected.

threshold stress (σ_{th})— a stress below which no hydrogen stress cracking will occur and above which time-delayed fracture will occur.

threshold stress intensity (K_{th})—a stress intensity below which no hydrogen stress cracking will occur and above which, time-delayed fracture will occur.

time-delayed embrittlement—see **internal hydrogen embrittlement**.

4.2 *Symbols:*

***P*—**applied load

P_c— critical load required to rupture a specimen using a continuous loading rate

P_i— crack initiation load for a given loading and environmental condition using an incrementally increasing load under displacement control

P_{th}— threshold load in which P_i is invariant with respect to loading rate; P_{th} is the basis for calculating the threshold stress or the threshold stress intensity

σ—applied stress

σ_{net}—net stress based on area at minimum diameter of notched round bar

σ_i—stress at crack initiation

$\sigma_{th\text{-}IHE}$—threshold stress—test conducted in air—geometry dependent

$\sigma_{th\text{-}EHE}$—threshold stress—test conducted in a specified environment—geometry dependent

***K*—**stress-intensity factor

K_{th}— threshold stress intensity

K_t— stress concentration factor

K_{Iscc}— threshold stress intensity for stress corrosion cracking

K_{IHE}— threshold stress intensity for IHE

K_{EHE}— threshold stress intensity for EHE

R_{sb}— ratio of specimen crack strength to yield strength in bending

R_{nsb}— ratio of specimen notched strength to yield strength in bending

***th*—**threshold

Σ_{th}—threshold stress

4.3 *Abbreviations:*

EAC—environmentally assisted cracking

EHE—environmental hydrogen embrittlement

ETUL—extended time under load

GHE—gaseous hydrogen embrittlement

HASC—hydrogen-assisted stress cracking

HSC—hydrogen stress cracking

Hsr—hydrogen susceptibility ratio

IHE—internal hydrogen embrittlement

HE—hydrogen embrittlement

NFS(B)—notched fracture strength in bending

NFS(T)—notched fracture strength in tension

NTS—notched tensile strength

ISL—incremental step load

ISL_{th}—threshold from an incremental step-load test

RA—reduction of area

RHE—reaction hydrogen embrittlement

SCC—stress corrosion cracking

SCE—saturated calomel electrode

SLT—sustained load test

ANNEX

(Mandatory Information)

A1. DEFINITIONS OF SYMBOLIC EXPRESSIONS

A1.1 The following abbreviations and symbols are included as separate sections in this standard because they evolved specifically from tests conducted on fasteners, which inherently have all of the ingredients necessary to create hydrogen embrittlement problems.

A1.2 Fasteners are generally (*1*) a notched, high-strength structural element that in service is always torqued to a high percentage of the fracture strength, (*2*) chemically cleaned, (*3*) coated with a sacrificial anodic coating that is generally electrochemically deposited producing a hydrogen charging condition, and (*4*) placed in service under cathodic charging conditions when exposed to an aqueous environment—all of the conditions necessary to cause classical hydrogen embrittlement (IHE) or environmentally induced hydrogen embrittlement (EHE).

A1.3 *Test Methods E8 Loading Rates*—These results are independent of any residual hydrogen concentration because the tests are performed at a rate that does not allow sufficient time for the diffusion of hydrogen to occur.

A1.3.1 *Tensile Test Symbols:*

TS(T) = tensile strength (tension), ksi; calculated from the minimum specified tensile strength (mst) and minor diameter of the fastener.

FS(T) = fracture strength (tension), ksi; calculated from the measured fracture or ultimate tensile load of the fastener, or notched or precracked test sample.

R_{nst} = notched strength ratio in tension; calculated from FS(T)/TS(T).

A1.3.2 *Bend Test Symbols:*

YS(B) = TS(T).

FS(B) = fracture strength (bend), ksi; calculated from the measured fracture or ultimate bend of the fastener, or notched or precracked test sample.

R_{nsb} = notched strength ratio in bending.

A1.4 *Test Method F1624 Loading Rates*—These abbreviations are used for the terms for results that are dependent on the residual hydrogen concentration. The tests are performed at a rate that allows sufficient time for the diffusion of hydrogen to occur.

A1.4.1 *ISL*—incremental step-load test to measure the threshold stress, which is slow enough to allow for the diffusion of hydrogen to occur.

A1.4.2 $\sigma_{th\text{-}air(T/B)}$— the threshold stress at a given loading rate measured in air in either tension or bend.

A1.4.3 $\sigma_{th\text{-}@V(T/B)}$— the threshold stress at a given loading rate measured at a given cathodic potential in either tension or bend.

A1.4.4 $\sigma_{th\text{-}H^{+}(T/B)}$—the lower limit of the threshold stress at an invariant loading rate measured in the most aggressive hydrogen charging environment of -1.2V versus SCE in either tension or bend.

A1.5 *Evaluation Parameter:*

A1.5.1 *%FS(T/B)*—degradation factor = % fracture strength.

A1.5.2 $H_{sr(T/B)}$—hydrogen susceptibility ratio, a material property that is a function of composition, melting practice, thermomechanical processing, heat treatment, and much more sensitive to microstructure than Test Methods E8 mechanical properties.

A1.5.3 $H_{sr(t/b)\text{-}IHE}$— the threshold notched hydrogen susceptibility ratio in either tension or bend for internal hydrogen embrittlement, (IHE).

A1.5.4 $H_{sr(t/b)\text{-}EHE}$— the threshold notched hydrogen susceptibility ratio in either tension or bend at a given cathodic potential for external or environmental hydrogen embrittlement, (EHE).

A1.5.5 $H_{sr(t/b)@\text{-}1.2V}$— the lower limit threshold notched hydrogen susceptibility ratio in either tension or bend for hydrogen-induced stress cracking in the most aggressive hydrogen charging environment of -1.2V versus SCE.

APPENDIX

(Nonmandatory Information)

X1. IHE/EHE COMPARISON CHART

TABLE X1.1 Similarities/Differences Between Internal (IHE) and Environmental (EHE) Hydrogen Embrittlement[A]

IHE	EHE
Time delay fracture when stressed in air after exposure to environment	Time delay fracture in environment after exposure to stress in air
Requires $[H]^{+}$ critical from processing (plating, acid cleaning) for a given stress above hydrogen stress cracking threshold	Requires $[H]^{+}$ critical from environment (cathodic corrosion reaction) for a given stress above hydrogen stress cracking threshold
Plating, acid cleaning, and so forth, considered environment in which "corrosion reaction" takes place to generate $[H]^{+}$, while stress is below threshold	"Corrosion reaction" takes place in environment to generate $[H]^{+}$, or other environmental sources of $[H]^{+}$, while stress is above threshold
The only difference between IHE and EHE is the sequence of applying the stress and exposure to hydrogen	
Phenomenon is the same! Mechanism is the same! Principle difference is sequence of stress and introduction of $[H]^{+}$ into the part!	
IHE: $[H]^{+}$ + Stress → Rupture EHE: Stress + $[H]^{+}$ → Rupture	

[A] If part was bent or plastically deformed to introduce residual stress before being put into a plating bath, and would have cracked during the plating process, it would have been identified as internal hydrogen embrittlement although having all the ingredients of environmental hydrogen embrittlement.

BIBLIOGRAPHY

The following documents and publications may provide additional definitions or terminology in the field of hydrogen embrittlement.

(1) Raymond, L., Ed., *Hydrogen Embrittlement Testing, ASTM STP 543*, ASTM, West Conshohocken, PA, 1972.
(2) Raymond, L., Ed., *Hydrogen Embrittlement: Prevention and Control, ASTM STP 962*, ASTM, West Conshohocken, PA, 1988 .
(3) "The Susceptibility of Fasteners to Hydrogen Embrittlement and Stress Corrosion Cracking," *Handbook of Bolts and Bolted Joints*, Marcel Decker, Inc., New York, 1998, Chap. 39, p. 723.
(4) ASTM Dictionary of Engineering Science & Technology, 10th Edition.