NACE Corrosion Engineer's Reference Guide

FOURTH EDITION

Robert Baboian

NACE INTERNATIONAL

NACE CORROSION ENGINEER'S REFERENCE BOOK

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Preface

The first edition of the NACE Corrosion Engineer's Reference Book was published in 1980 and was conceived and edited by Richard (Dick) Treseder. He oversaw the revision of that edition to produce the second edition, co-edited by Robert Baboian and Charles (Chuck) Munger, which was published in 1991. The third edition, edited by Robert Baboian, was an extensive and complete revision of the previous edition with new and updated sections.

The fourth edition, also edited by Robert Baboian, is an extensive revision and update of the third edition with new data, tables, and figures.

The objective of the NACE Corrosion Engineer's Reference Book is to provide scientists, engineers, technologists, and students with useful and important information and data on corrosion investigation and control. The book is designed to be carried with the user so that the contents are readily available.

NACE International thanks the numerous sources of information and data who have given permission for use in this book. These sources are identified in footnotes following the individual tables and graphs.

Contents

4. CORROSION TESTING

5. CORROSION EVALUATION

6. ATMOSPHERIC CORROSION

7. SEAWATER AND COOLING WATER CORROSION

8. CATHODIC PROTECTION

9. PROCESS AND OIL INDUSTRIES CORROSION

10. METALLIC MATERIALS

11. NONMETALLIC MATERIALS

12. PROTECTIVE COATINGS

1
Glossary

NACE/ASTM STANDARD TERMINOLOGY RELATING TO CORROSION

abrasion resistance—the ability of a material to resist being worn away and to maintain its original appearance and structure when subjected to rubbing, scraping, or wear.

abrasive—a solid substance that, owing to its hardness, toughness, size, shape, consistency, or other properties, is suitable for grinding, cutting, roughening, polishing, or cleaning a surface by friction or high-velocity impact.

abrasive blast cleaning—cleaning and roughening of a surface produced by the high-velocity impact of an abrasive that is propelled by the discharge of pressurized fluid from a blast nozzle or by a mechanical device such as a centrifugal blasting wheel. [Also referred to as abrasive blasting.]

abrasive blasting—see abrasive blast cleaning.

accelerator—a chemical substance that increases the rate at which a chemical reaction (e.g., curing) would otherwise occur.

AC impedance—see electrochemical impedance.

acrylic—type of resin polymerized from acrylic acid, meth-acrylic acid, esters of these acids, or acrylonitrile.

activator—a chemical substance that initiates a chemical reaction (e.g., curing). Heat and radiation may also serve as activators for some chemical reactions.

active—*(1)* a state of a metal surface that is corroding without significant influence of reaction product. *(2)* the negative direction of electrode potential.

active-passive cell—an electrochemical cell in which the anode is a metal in the active state and the cathode is the same metal in the passive state.

adduct curing agent—a material that is formed by pre-reacting the curing agent with a portion of the resin component of the coating.

adhesion—the state in which two surfaces are held together by chemical interfacial forces, mechanical interlocking forces, or both.

aeration cell—see differential aeration cell.

aging—*(1)* the process of exposing materials to an environment for an interval of time. *(2)* change in metallurgical properties that generally occurs slowly at room temperature (natural aging) and more rapidly at higher temperature (artificial aging).

air drying—process by which an applied wet coat converts to a dry coating film by evaporation of solvent or reaction with oxygen as a result of simple exposure to air without intentional addition of heat or a curing agent.

airless spraying—process of spraying coating liquids using hydraulic pressure, not air pressure, to atomize.

alkyd—type of resin formed by the reaction of polyhydric alcohols and polybasic acids, part of which is derived from saturated or unsaturated oils or fats.

alligatoring—pronounced wide cracking over the surface of a coating, which has the appearance of alligator hide.

alloy steel—an iron-based alloy containing carbon (usually less than 2.5 mass percent), manganese (usually greater than 0.25 mass percent), and specified minimum quantities of one or more alloying elements other than manganese, silicon, and copper, but does not contain 10.5 mass percent or greater chromium.

alternate immersion—exposure to environmental cycles, each involving immersion in a fluid for a period of time followed by removal from that fluid for another period of time.

amphoteric metal—a metal that is susceptible to corrosion in both acidic and alkaline environments.

anaerobic—absence of air or free (molecular) oxygen.

anchor pattern—see surface profile.

anion—a negatively charged ion.

anneal—heat to and hold at a temperature appropriate for the specific material and then cool at a suitable rate, for such purposes as reducing hardness, improving machinability, or obtaining desired properties.

anode—the electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.)

anode cap—an electrical insulating material placed over the end of the anode at the lead wire connection.

anode corrosion efficiency—the ratio of the actual corrosion (mass loss) of an anode to the theoretical corrosion (mass loss) calculated from the quantity of electricity that has passed between the anode and cathode using Faraday's law.

anodic inhibitor—a corrosion inhibitor whose primary action is to reduce the rate of the anodic reaction, producing a positive shift in corrosion potential.

anodic polarization—*(1)* the change of electrode potential caused by an anodic current flowing across the electrode/electrolyte interface. *(2)* a forced noble (positive) shift in electrode potential. [See polarization.]

anodic protection—a technique to reduce the corrosion rate of a metal surface by polarizing that surface to a more oxidizing potential.

anodizing—an electrochemical oxidation process that converts the surface of a metal (such as aluminum or titanium) to an oxide coating.

anolyte—the electrolyte adjacent to the anode of an electrochemical cell.

antifouling—preventing fouling. [See fouling.]

atmospheric zone—the portion of a marine structure that extends upward from the splash zone and is exposed to sun, wind, water spray, and rain.

attenuation—electrical losses in a conductor caused by current flow in the conductor.

Auger electron spectroscopy—analytical technique in which the sample surface is irradiated with low-energy electrons and the energy spectrum of electrons emitted from the surface is measured.

austenite—the face-centered cubic crystalline phase of iron or iron-based alloys.

austenitic/ferritic stainless steel—see duplex stainless steel.

austenitizing—forming austenite by heating iron or iron-based alloys to a temperature in the transformation range (partial austenitizing) or above the transformation range (complete austenitizing).

auxiliary electrode—see counter electrode.

backfill—material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system.

Barcol hardness—a hardness value obtained by measuring the resistance of rubbers, plastics, or coatings to indentation by a steel impressor under spring load in accordance with Test Method D2583.

barrier coating—*(1)* a coating that has a high resistance to permeation of liquids and/or gases. *(2)* a coating that is applied over a previously coated surface to prevent damage to the underlying coating during subsequent handling.

barrier pigment—a pigment that impedes permeation through an organic coating solely by its physical presence. [contrast with corrosion-inhibitive pigment and sacrificial pigment]

beach marks—the characteristic markings on the fracture surfaces produced by fatigue crack propagation. [Also known as *arrest marks*, *clamshell marks*, and *conchoidal marks*]

beta curve—a plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate) versus the corresponding structure-to-electrolyte potentials at a selected location on the affected structure (abscissa).

binder—the nonvolatile portion of the vehicle of a formulated coating material.

bituminous coating—an asphalt or coal-tar compound used to provide a protective coating for a surface.

blast angle—*(1)* the angle of the blast nozzle with reference to the surface during abrasive blast cleaning. *(2)* the angle of the abrasive particles propelled from a centrifugal blasting wheel with reference to the surface being abrasive blast cleaned.

blister—a dome-shaped projection on the surface of a coating resulting from the local loss of adhesion and lifting of the film from an underlying coat or from the base substrate.

blooming—see blushing.

blowdown—*(1)* the injection of air or water under high pressure through a tube to the anode area for the purpose of purging the annular space and possibly correcting high resistance caused by gas blockage. [cathodic protection use] *(2)* the process of discharging a significant portion of the aqueous solution in order to remove accumulated salts, deposits, and other impurities. [boiler or cooling water tower use]

blushing—whitening and loss of gloss of a coating, usually organic, caused by moisture. [Also known as blooming.]

bracelet anode—a galvanic anode with geometry suitable for direct attachment around the circumference of a pipeline. This may be a half-shell bracelet consisting of two semicircular sections or a segmented bracelet consisting of a large number of individual sections.

braze—*(1)* a bond produced as the result of heating an assembly to the brazing temperature greater than 450 °C [840 °F] and less than the solidus temperature of the base metal using a brazing filler metal distributed and retained between the closely fitted faying surfaces of the joint by capillary

action. *(2)* the act of creating a braze.

breakdown potential—the least noble potential at which pitting or crevice corrosion, or both, will initiate and propagate in a specific environment.

Brinell hardness—hardness value, measured in accordance with ISO 6506-1 or Test Method E10, using a 1 to 10 mm diameter tungsten carbide ball and a force of approximately 9.807 to 29.420 N (1 to 3,000 kgf).

brittle fracture—fracture that occurs with little or no plastic deformation of the material. [contrast with ductile fracture]

brush-off blast cleaned surface—an abrasive blast cleaned steel surface that is free of all visible contaminants and foreign matter but may have some tightly adherent mill scale, rust, or coating. [See NACE No. 4/SSPC-SP 7 for detailed specification.]

burnish—process of smoothing surfaces using frictional contact between the material and some other hard pieces of hard material (e.g., hardened steel balls).

calcareous coating—a layer consisting of calcium carbonate and other salts deposited on the surface. When the surface is cathodically polarized as in cathodic protection, this layer is the result of the increased pH adjacent to the protected surface.

calcareous deposit—see calcareous coating.

carbon steel—alloy of carbon and iron containing up to 2 mass percent carbon and up to 1.65 mass percent manganese and residual quantities of other elements, except those intentionally added in specific quantities for deoxidation (usually silicon and/or aluminum).

carburizing—the absorption and diffusion of carbon in iron or an iron-based alloy in contact with a suitable carbonaceous environment at elevated temperature.

case hardening—hardening a ferrous alloy so that the outer portion, or case, is made substantially harder than the inner portion, or core. Typical processes are carburizing, cyaniding, carbonitriding, nitriding, induction hardening, and flame hardening.

casein paint—water-thinned paint with vehicle derived from milk.

cast iron—a generic term for a large family of cast ferrous alloys in which the carbon content exceeds the solubility of carbon in austenite at the eutectic temperature, or about 2 mass percent. Most cast irons also contain silicon, and may contain other alloying elements and impurities.

casting—*(1)* a component formed at or near its finished shape by the solidification of liquid material in a mold; *(2)* the creation of such a component.

catalyst—a chemical substance, usually present in small amounts relative to the reactants, that increases the rate at which a chemical reaction (e.g., curing) would otherwise occur, but is not consumed in the reaction.

cathode—the electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.)

cathodic corrosion—corrosion of a metal when it is a cathode, usually caused by the reaction of an amphoteric metal with the alkaline products of electrolysis.

cathodic disbondment—the destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

cathodic inhibitor—a corrosion inhibitor whose primary action is to reduce the rate of the cathodic reaction, producing a negative shift in corrosion potential.

cathodic polarization—*(1)* the change of electrode potential caused by a cathodic current flowing

across the electrode/electrolyte interface. *(2)* a forced active (negative) shift in electrode potential. [See polarization.]

cathodic protection—a technique to reduce the corrosion rate of a metal surface by making that surface the cathode of an electrochemical cell.

catholyte—the electrolyte adjacent to the cathode of an electrochemical cell.

cation—a positively charged ion.

caustic cracking—cracking of a metal or alloy under the combined action of tensile stress and corrosion in the presence of a strongly basic solution (e.g., sodium hydroxide, potassium hydroxide).

caustic embrittlement—an obsolete term referring to caustic cracking.

cavitation—the formation and rapid collapse of cavities or bubbles of vapor or gas within a liquid resulting from mechanical or hydrodynamic forces.

cavitation-corrosion—the conjoint action of cavitation and corrosion.

cavitation damage—the degradation of a solid body resulting from its exposure to cavitation. (This may include loss of material, surface deformation, or changes in properties or appearance.)

cavitation-erosion—the conjoint action of cavitation and erosion.

cell—see electrochemical cell.

cementation—the introduction of one or more elements into the surface layer of a metal or alloy by diffusion at high temperature. (Examples of cementation include carburizing [introduction of carbon], nitriding [introduction of nitrogen], and chromizing [introduction of chromium].)

cementite—iron carbide (Fe_3C) when referred to as a microstructural constituent of steel.

chalking—the development of loose, removable powder (pigment) at the surface of an organic coating, usually caused by weathering.

checking—the development of slight breaks in a coating that do not penetrate to the underlying surface.

chemical conversion coating—an adherent, reaction-product layer on a metal surface formed in situ by reaction with a suitable chemical, used for protective, decorative, or functional purposes. (It is often used to provide greater corrosion resistance or prepare the surface prior to the application of an organic coating.)

chevron pattern—a V-shaped pattern on a fatigue or brittlefracture surface. The pattern can also be one of straight radial lines on cylindrical specimens.

chipping—*(1)* removing coating and surface contaminants from a substrate in small pieces by cutting, striking, or applying mechanical force; *(2)* a failure mechanism in which small pieces or fragments of a material or coating are removed by mechanical damage, loss of adhesion, or both. [contrast with peeling]

chloride stress corrosion cracking—cracking of a metal under the combined action of tensile stress and corrosion in the presence of an electrolyte-containing dissolved chlorides.

cleavage fracture—fracture that occurs along planes determined by the crystal structure of the material. (It is typically associated with a brittle fracture.)

coat—one layer of a coating system applied to a surface in a single continuous application to form a uniform film when dry.

coating—*(1)* a liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. *(2)* (in a more general