The following excerpt are pages from the North American Product Technical Guide, Volume 2: Anchor Fastening, Edition 17.

Please refer to the publication in its entirety for complete details on this product including data development, product specifications, general suitability, installation, corrosion and spacing and edge distance guidelines.
US: http://submittals.us.hilti.com/PTGVol2/
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To consult directly with a team member regarding our anchor fastening products, contact Hilti's team of technical support specialists between the hours of 7:00am – 6:00pm CST.
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2.3 Corrosion

2.3.1 The corrosion process

Corrosion is defined as the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties (ASTM G15). The corrosion process can be very complex and have many contributing factors that lead to immediate or gradual destructive results.
In anchorage and fastener design, the most common types of corrosion are direct chemical attack and electro-chemical contact.

2.3.2 Types of corrosion

2.3.2.1 Direct chemical attack

Corrosion by direct chemical attack occurs when the base material is soluble in the corroding medium. One method of mitigating these effects is to select a fastener that is not susceptible to attack by the corroding chemical. Compatibility tables of various chemical compounds with Hilti adhesive and epoxy fastening systems are provided in this technical guide.

When selection of a base metal compatible with the corroding medium is not possible or economical, another solution is to provide a coating that is resistant to the corroding medium. This might include metallic coatings such as zinc or organic coatings such as epoxies or fluorocarbons.

2.3.2.2 Electrochemical contact corrosion

All metals have an electrical potential relative to each other and are classified accordingly in the galvanic series of metals and alloys. When metals of different potential come into contact in the presence of an electrolyte (moisture), the metal with more negative potential becomes the anode and corrodes, while the other becomes the cathode and is galvanically protected.

The severity and rate of attack are influenced by:

a. Relative position of the contacting metals in the galvanic series

b. Relative surface areas of the contacting materials

c. Conductivity of the electrolyte

The effects of electro-chemical contact corrosion may be mitigated by:

a. Using similar metals close together in the electromotive force series,

b. Separating dissimilar metals with gaskets, plastic washers or paint with low electrical conductivity. Materials typically used in these applications include:

1. High Density Polyethylene (HDPE)
2. Polytetrafluoroethylene (PTFE)
3. Polycarbonates
4. Neoprene/chloroprene
5. Cold galvanizing compound
6. Bituminous coatings or paint

Note: Specifiers must ensure that these materials are compatible with other anchorage components in the service environment.

c. Selecting materials so that the fastener is the cathode, the most noble or protected component

d. Providing drainage or weep holes to prevent entrapment of the electrolyte

Galvanic series of metals and alloys
Corroded End (anodic, or least noble)
Magnesium Magnesium alloys Zinc
Aluminum 1100 Cadmium Aluminum 2024-T4 Steel or iron Cast Iron Chromium-iron (active) Ni-Resist cast iron
Type 304 stainless (active) Type 316 stainless (active)
Lead tin solders Lead Tin
Nickel (active) Inconel nickel-chromium alloy (active) Hastelloy alloy C (active)
Brasses Copper Bronzes Copper-nickel alloys Monel nickel-copper alloy
Silver solder Nickel (passive) Inconel nickel-chromium alloy (passive)
Chromium-iron (passive) Type 304 stainless (passive) Type 316 stainless (passive) Hastelloy alloy C (passive)
Silver Titanium Graphite Gold Platinum
Protected end (cathodic, or most noble)

Source: IFI Fastener Standards, 6th edition

2.3.2.3 Hydrogen assisted stress corrosion cracking

Often incorrectly referred to as hydrogen embrittlement, hydrogen assisted stress corrosion cracking (HASCC) is an environmentally induced failure mechanism that is sometimes delayed and most times occurs without warning. HASCC occurs when a hardened steel fastener is stressed (loaded) in a service environment which chemically generates hydrogen (such as when zinc and iron combine in the presence of moisture). The potential for HASCC is directly related to steel hardness. The higher the fastener hardness, the greater the susceptibility to stress corrosion cracking failures. Eliminating or reducing any one of these contributing factors (high steel hardness, corrosion or stress) reduces the overall potential for this type of failure. Hydrogen embrittlement, on the other hand, refers to a potential damaging side effect of the steel fastener manufacturing process, and is unrelated to project site corrosion. Hydrogen embrittlement is neutralized by proper processing during fastener pickling, cleaning and plating operations (specifically, by "baking" the fasteners after the application of the galvanic coating).

2.3.3 Corrosion protection

The most common material used for corrosion protection of carbon steel fasteners is zinc. Zinc coatings can be uniformly applied by a variety of methods to achieve a wide range of coating thickness depending on the application. All things being equal, thicker coatings typically provide higher levels of protection.

An estimating table for the mean corrosion rate and service life of zinc coatings in various atmospheres is provided to the right. These values are for reference only, due to the large variances in the research findings and specific project site conditions, but they can provide the specifier with a better understanding of the expected service life of zinc coatings. In controlled environments where the relative humidity is low and no corrosive elements are present, the rate of corrosion of zinc coatings is approximately 0.15 microns per year.

Zinc coatings can be applied to anchors and fasteners by different methods. These include (in order of increasing coating thickness and corrosion protection):

a. ASTM B633 – Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel

b. ASTM B695 – Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel

c. ASTM A153 – Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware

d. Sherardizing Process – Proprietary Diffusion Controlled Zinc Coating Process

Atmosphere	Mean corrosion rate
Industrial	5.6 µm/year
Urban non-industrial or marine	1.5 µm/year
Suburban	1.3 µm/year
Rural	0.8 µm/year
Indoors	Considerably less than 0.5 µm/year

Source: ASTM B633 Appendix X1. Service life of zinc

2.3.3.1 Suggested corrosion resistance

Use of AISI 316 stainless steel in environments where pitting or stress corrosion is likely to occur should be avoided due to the possibility of sudden failure without visual warning. Fastenings used in these applications should be regularly inspected for serviceability conditions. See chart below for more details.

Corrosion resistance	Typical conditions of use
Phosphate and oil coatings (Black oxide)	• Interior applications without any particular influence of moisture
Zinc electro-plated 5 – 10 µm (ASTM B633, SC 1, Type III) Organic coatings – KWIK Cote≥17.8 µm	• Interior applications without any particular influence of moisture • If covered sufficiently by noncorrosive concrete
Mechanically deposited zinc coating 40 – 107 µm	• Interior applications in damp environments and near saltwater (ASTM B695)
Hot-dip galvanizing (HDG) >50 µm (ASTM A153) Sherardizing process > 50 µm	• Exterior applications in only slight to mild corrosive atmospheres
Stainless steel (AISI 303 / 304)	• Interior applications where heavy condensation is present • Exterior applications in corrosive environments
Stainless steel (AISI 316)	• Near saltwater • Exterior corrosive environments

2.3 Corrosion

2.3.4 Test methods

Various test methods have been used in the development of Hilti fastening systems to predict their performance in corrosive environments. Some of the internationally accepted standards and test methods used in these evaluations are:

a. ASTM B117 Standard Practice for Operating Salt Spray (Fog) Apparatus

b. ASTM G85 Standard Practice for Modified Salt Spray (Fog) Testing

c. ASTM G87 Standard Practice for Conducting Moist SO_2 Tests

d. DIN 50021 - SS Salt Spray Testing (ISO 3768)

e. DIN 50018 - Kesternich Test (ISO 6988) Testing in a Saturated Atmosphere in the Presence of Sulfur Dioxide

2.3.5 Hilti fastening systems

2.3.5.1 Anchors

Most Hilti metal anchors are available in carbon steel with an electrodeposited zinc coating of at least 5 µm with chromate passivation. Chromate passivation reduces the rate of corrosion for zinc coatings, maintains color, abrasion resistance and, when damaged, exhibits a unique “self healing” property. This means that the chromium contained within the film on the anchor surface will repassivate any exposed areas and lower the corrosion rate.

Hilti HAS-E-B high strength threaded rods in 7/8-in. diameter size and KWIK Bolt 3 mechanical anchors are zinc coated by the hot-dip galvanizing process. Other sizes may be available through special orders.

Stainless steel anchors should be considered as the fastening solution whenever the possibility for corrosion exists. It must be noted that under certain extreme conditions, even stainless steel anchors will corrode and additional protective measures will be needed. Stainless steels should not be used when the anchorage will be subjected to long term exposure, immersion in chloride solutions, or in corrosive environments where the average temperature is above 86° F. Hilti High Corrosion Resistant (HCR) threaded rod is available on a special order basis. Its composition provides superior corrosion resistance compared to AISI 316 and is an alternative to titanium or other special stainless steels.

Chapter 19 of ACI 318-14 provides additional information for concrete durability requirements.

2.3.6 Applications

It is difficult to offer generalized solutions to corrosion problems. A general guide can be used as a starting point for fastener material selection based on the desired application. The specifier should also consult:

a. Local and national building code requirements (e.g., IBC, UBC)

b. Standard practice manuals for specific types of construction (e.g., ACI, PCI, AISC, PCA, CRSI, AASHTO, NDS/APA)

c. Manufacturers of structural components

d. Hilti Technical Support

2.3.6.1 General applications

These application charts are offered as general guidelines.[4] Site specific conditions may influence the decision.

Application	Conditions	Fastener recommendations
Structural steel components to concrete and masonry (interior connections within the building envelope not subjected to free weathering)[1,2]	Interior applications without condensation	Galvanic zinc electroplating
	Interior applications with occasional condensation	HDG or Sherardized
Structural steel components to concrete and masonry (exterior connections subjected to free weathering)[1,2]	Slightly corrosive environments	HDG or Sherardized
	Highly corrosive environments	Stainless steel
Temporary formwork, erection bracing and short-term scaffolding	Interior applications	Galvanic zinc electroplating
	Exterior applications	HDG or Sherardized
Parking garages / parking decks subject to periodic application of de-icers including chloride solutions[3]	Non-safety critical	HDG, Sherardized
	Safety critical	Stainless steel[1]
Road / bridge decks subject to periodic application of de-icers including chloride solutions	Non-safety critical	HDG or Sherardized
	Safety critical	Stainless steel

1 Refer to ACI 318-14 Chapter 19 – Durability

2 Refer to ACI 530.1 Section 2.4F – Coatings for Corrosion Protection

3 Refer to PCI Parking Structures: Recommended Practice for Design and Construction – Chapters 3, 5 and Appendix

4 General guidelines address environmental corrosion (direct chemical attack). Additional considerations should be taken into account when using hardened steel fasteners susceptible to HASCC.

2.3.6.2 Special applications

These application charts are offered as general guidelines.[4] Site specific conditions may influence the decision.

Application	Conditions	Fastener recommendations
Aluminum fastenings (flashing / roofing accessories, hand rails, grating panels, sign posts and miscellaneous fixtures)	Interior applications without condensation	Galvanic zinc electroplating
	Exterior applications with condensation	Stainless steel
Water treatment	Not submerged	HDG, sherardized, stainless steel
	Submerged	Stainless steel[2]
Waste water treatment	Not submerged	HDG, sherardized, stainless steel
	Submerged	Stainless steel[2]
Marine (salt water environments, shipyards, docks, off-shore platforms)	Non-safety critical or temporary connections	HDG, sherardized
	High humidity with the presence of chlorides – splash zone	Stainless steel[1]
	On the off-shore platform or rig	Stainless steel
Indoor swimming pools	Non-safety critical	HDG, sherardized
	Safety critical or subjected to high concentrations of soluble chlorides	Stainless steel[1]
Pressure / chemically treated wood[3]	Above grade	HDG
	Below grade	Stainless steel
Power plant stacks / chimneys	Non-safety critical	HDG, stainless steel
	Safety critical or subjected to high	Stainless steel
Tunnels (lighting fixtures, rails, guardposts)	Non-safety critical	HDG, stainless steel
	Safety critical	Stainless steel[1]

1 Steel selection depends on safety relevance

2 Must electrically isolate fastener from contact with concrete reinforcement through use of adhesive or epoxy anchoring system, gasket or plastic washer with low electrical conductivity

3 Refer to APA Technical Note No. D485D and AF and PA Technical Report No. 7

4 General guidelines address environmental corrosion (direct chemical attack). Additional considerations should be taken into account when using hardened steel fasteners susceptible to HASCC.