TPIC Technical Bulletin #4

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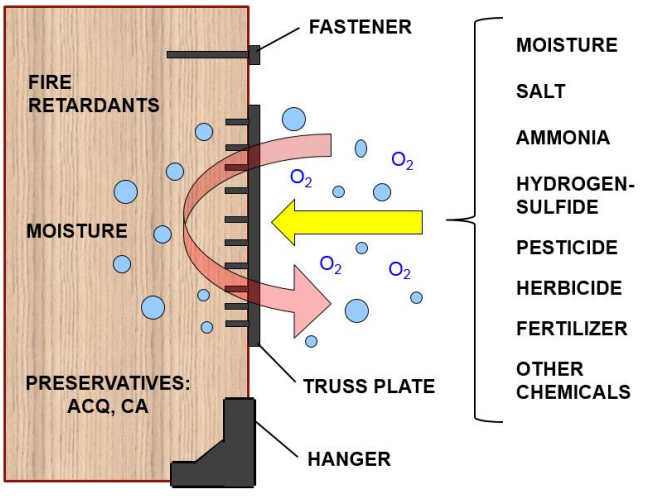
Design for Corrosive Environments

Introduction

For the majority of applications, metal plate connected wood trusses are designed for interior, above ground, dry service conditions. They are typically not being exposed to corrosive environments such as wet service conditions, preservative treated lumber, salt storage facilities, corrosion-susceptible farm buildings, and swimming pools. Corrosive environments tend to reduce the strength and longevity of the metal connectors and thus the truss system as a whole.

What is Corrosion?

Corrosion is the destructive degradation of a material by reaction with its environment (Roberge 2000). Here the material is the connector and the environment is whatever the connector interacts with, namely wood and air. Each environment may contain one or more corrodents (substances that cause corrosion) acting independently or in combination to degrade the strength of the connectors.



Electrochemical oxidation is the most common type of corrosion affecting metal connectors. It is a process in which iron (Fe) reacts with oxygen (O_2) in the presence of an electrolyte such as water (H_2O) to form iron oxide (Fe_2O_3), commonly known as rust.

Most connectors are made of steel, an iron-based metal alloy. As such, they are susceptible to this type of corrosion, even when exposed to normal atmospheric air, which contains oxygen and water as part of its normal composition. Over time, the continuous formation of rust eats away the base metal and thereby reduces the strength of the connectors. The rate of oxidation generally increases with increasing moisture content, the presence of salt, and when galvanic corrosion is a contributing factor.

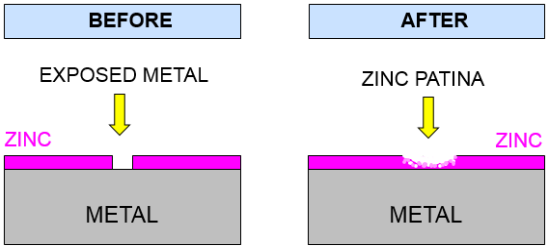
Galvanic Series (Abbreviated)
More Active (Anodic-)
Zinc
Aluminum
Steel
Brass
Copper
Nickel
Stainless Steel - Type 304
Stainless Steel - Type 316
More Passive (Cathodic +)

Galvanic corrosion occurs when there is an interaction between dissimilar metals. The degree of corrosion depends on where the metals reside in the galvanic series, which is a compilation of known metals and their relative reactivity. The more active metal (anode) will corrode preferentially while shielding the more passive metal (cathode) from further degradation (AGA 2011).

Corrosion Protection

Zinc Galvanizing:

Connectors are manufactured from zinc galvanized sheet steel. The punching and shearing processes create many exposed bare metal surfaces, particularly at the teeth, slots, and exterior edges. Thankfully, zinc has the ability to 'heal' itself; the zinc around the exposed metal corrodes and deposits a layer of corrosion by-product called zinc patina (white powdery appearance) over the exposed metal to protect it.

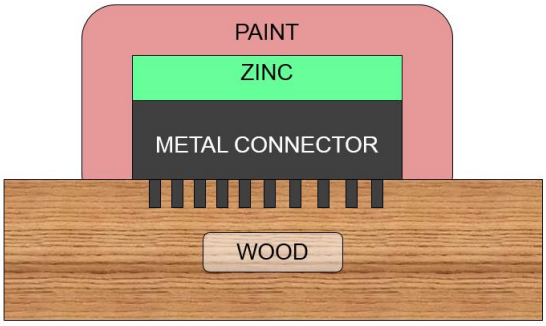


By being more reactive than steel, zinc sacrificially corrodes at a steady rate over time to shield the steel from the effect of corrosion. The protection ability of zinc is proportional to its thickness, which is proportional to the amount of zinc applied (ASTM 2018).

Weight and Thickness of Zinc Coatings		
Coating	**Weight (oz/ft^2) on Both Sides**	**Thickness on One Side**
G90	0.90	0.00076" (0.019 mm)
G185	1.85	0.00155" (0.039 mm)

Duplex System:

A duplex system is formed by applying paint over G90 or G185 connectors. The corrosion protection ability of a duplex system is superior to the combined lifespan of paint and zinc applied independently due to the synergistic effect between these coatings. While the paint provides barrier protection to shield the zinc from the corrodents, the zinc provides a continuously protected surface under the paint to minimize peeling of the paint itself (AGA 2012).



The key to a successful duplex system is to carefully prepare the galvanized surface before applying the coating.

The following procedure is recommended:

- Remove dirt, debris, and chromate (if any) from the connectors. Do not use any surface preparation method that can damage the connectors or lumber.
- Use approved paints, such as those conforming to the SSPC Paint 16 standard (coal tar epoxy polyamide black or dark red) .
- Apply paint on top of the galvanized (G90 or G185) connectors. All coatings shall be brush applied to the embedded connectors during or after truss installation.

Stainless Steel:

By having 10% or more of chromium in its material composition, stainless steel is able to achieve superior resistance against corrosion compared to all other materials and coatings, but it is also one of the most expensive options available.

Preventive Measures:

While adequate ventilation reduces the accumulation of moisture and corrodents, a separate ventilation system and vapour barrier prevent the corrodents from reaching the connectors and lumber in the first place. The following are effective preventive measures known to extend the serviceable life of the connectors and truss assembly:

- Install a vapour barrier, such as 4-6 mil polyethylene, to completely cover the truss assembly; all seams are taped and all gaps are covered to prevent the corrodents from entering the attic space.
- Ventilate the interior and attic spaces separately. The ventilation system should supply plenty of fresh air to move moisture and corrosive gasses away from the interior space; the exhaust ducts should be located far away from the attic's ventilation openings.
- Typically, insulation is also required inside the attic space to prevent condensation.
- Periodic inspection is advised to look for leakage through the vapour barrier and corrosion on the connectors. Once corrosion is detected, take the appropriate steps to remove the corrodents from the attic space or provide additional protection for the connectors. Annual inspection frequency is recommended at minimum.

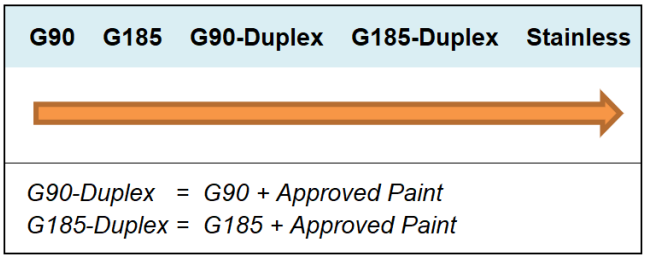
Design Guidelines:

Where there are governing national, provincial, or local building code requirements, the application and selection of the connectors and strength modification factors shall comply with these requirements. Design guidelines for various corrosive environments are presented, but it is the responsibility of the building designer/engineer to determine the most viable solution based on a detailed evaluation of the vulnerability of the truss system to the specific corrosive environment.

The guidelines below consist of best practices, recommended protection, and strength modification factors, where applicable. Where there are multiple options suggested, the lower protection level is intended to address less severe conditions while the higher protection level is meant to address more severe conditions. Do not automatically default to the lowest protection level. Select the option that eliminates or adequately reduces the vulnerability of the truss system to the corrodents. When in doubt, use a higher level of protection than anticipated or seek professional consultation.

Relative Corrosion Resistance:

The Society for Protective Coatings (SSPC) conducted extensive research to evaluate the performance of various coatings applied over galvanized connector plates. They found that certain paints applied over G60 connectors outperformed connectors with zinc coating exceeding G185 specification (SSPC 1989). Since G90 offers better protection than G60, a G90-duplex system (G90 + paint) will resist corrosion better than G60-duplex; likewise, G185-duplex is better than G90-duplex. The chart below ranks the available options in terms of their relative effectiveness against corrosion. Stainless steel remains the most corrosion-resistant option available.



Galvanic Corrosion:

The simplest solution to minimize galvanic corrosion is to make sure that the components that are in direct contact with each other are made of the same material or coating. Once this is achieved, galvanic corrosion is eliminated or significantly reduced. This is why manufacturers typically recommend using fasteners and connectors of the same material or surface coating. For example, use galvanized nails for galvanized connectors and stainless steel nails for stainless steel connectors.

Preservative (Pressure) Treated Wood:

Research has shown that ACQ (alkaline copper quaternary) and CA (copper azole) are corrosive to metal connectors, while borates-based preservatives (such as SBX or DOT) are no more corrosive than untreated lumber. G90-Duplex is not suitable for these preservatives because the paint is only covering the exterior surfaces and not the embedded teeth. G185 is the minimum protection for use with ACQ and CA treated lumber classified under the Use Category System UC4.1 and lower (CAN/CSA O80.1). For treated lumber classified as UC4.2 and greater, stainless steel may be required.

Guideline for ACQ or CA Treated Wood (UC4.1)	
Protection	**Comment**
G185 G185-Duplex Stainless Steel	Apply strength modification factors for wet service when using green lumber or used under wet service condition.

Fire Retardant Treated (FRT) Wood:

Although most common fire retardants used in truss applications are not corrosive to the metal connectors, not all products are non-corrosive. Additionally, they typically require proprietary strength reductions applied to the lumber in accordance with the manufacturer's specifications. Since the lumber strength is lower, the grip resistance of the connector must also be reduced accordingly. It is important to note that some fire retardants cause the wood to absorb more moisture from the air than untreated lumber. Consequently, the metal connectors may be exposed to a higher level of moisture, resulting in more corrosion.

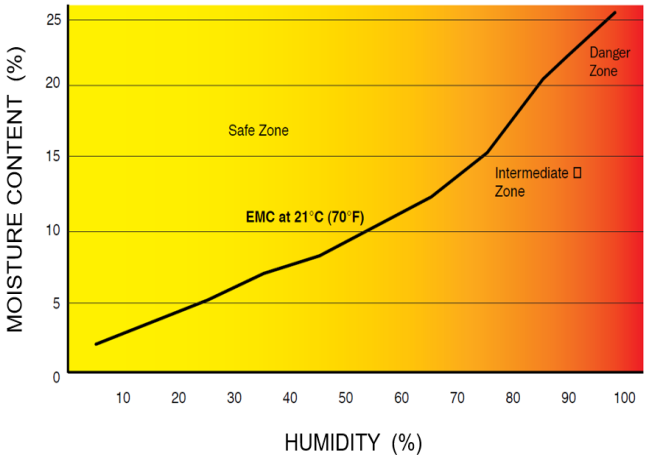
Strength Reducing Chemicals:

These include organic acids, inorganic acids, oxidizing/reducing agents, alkaline solutions, or any chemical that has the net effect of degrading the strength of the connectors. While weak chemicals degrade connectors over long periods of time, stronger chemicals can quickly consume the connectors and lead to catastrophic failure. Moreover, the interaction between the reactants can be very complex; a protective coating that works for some chemicals may not work for others. As such, whenever trusses are exposed to this type of chemicals, it is recommended that the appropriate professionals be consulted in advance.

Wet Service Condition:

CSA O86 defines wet service condition as any service condition other than dry; dry service is a climatic condition in which the average equilibrium moisture content of solid wood over a year is 15% or less and does not exceed 19% (CSA 2019). As shown in the graph below, in order to get above 19% moisture in the lumber, the relative humidity in the air needs to reach about 80% or higher, depending on wood species and temperature.

WOOD MOISTURE CONTENT VS HUMIDITY



Source: Canadian Wood Council (CWC) Publication: "Managing Moisture and Wood"

Unfortunately, 80% is above the critical humidity level for the electrochemical oxidation of steel, which is around 60% (Roberge 2000). Beyond 60%, the rate of corrosion increases due to an increase in available moisture to facilitate the corrosion process. The service condition factors shall be applied to both the lumber and connector whenever there is wet service condition (CSA 2019). Note that G90 is omitted from consideration because it may not be suitable for use in wet service.

Guideline for Wet Service Condition		
Strength Properties		**Service Condition Factor**
Lumber:		
K_{Sb}	Bending at extreme fibre	0.84
K_{Sv}	Longitudinal shear	0.96
K_{Sc}	Compression parallel to grain	0.69
K_{Scp}	Compression perpendicular to grain	0.67
K_{St}	Tension parallel to grain	0.84
K_{SE}	Modulus of elasticity	0.94
Connector: G185, G90-Duplex, G185-Duplex, Stainless		
K_{SF}	Ultimate Lateral resistance of teeth	0.67
	Lateral Slip resistance of teeth	0.67

Salt Storage Facilities:

These are buildings used for the storage of bulk salt/sand mixture for roads/highways maintenance. It is reasonable to expect that the truss may be exposed to both the corrosive effect of salt and wet service condition even though the amount of moisture within the buildings may vary from time to time depending on the composition of the mixture and the design, ventilation performance, and geographic location of each building.

Guideline for Salt Storage Facilities	
Protection	**Comment**
G90-Duplex G185-Duplex Stainless Steel	Apply strength modification factors for wet service condition unless appropriate measures are taken to ensure dry service condition.

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Farm Buildings:

The buildings most susceptible to accelerated corrosion are naturally ventilated swine, beef, and dairy barns with slatted floors and deep manure storages (OMAFRA 2010). There are two principle modes of corrosion occurring: first from the wet service condition created by the large quantity of moisture exhaled by the animals, and second from the corrosive chemicals that are normally found in these types of farms. These chemicals include, but are not limited to, gaseous ammonia (NH_3) and hydrogen sulfide (H_2S) generated from the waste of animals (Jofriet et al, 2003). In other applications, connectors exposed to agricultural chemicals such as fertilizers, herbicides, and pesticides may also experience accelerated corrosion. Whenever farm trusses are exposed to wet service condition, apply the applicable strength modification factors for the lumber and connectors; G185 is the minimum protection required for wet service.

Guideline for Farm Buildings	
Environment	**Protection**
Low Corrosion: Low exposure to moisture, organic gases, and chemicals, such as grain/hay/ equipment storage.	Use G90 connectors. Provide ventilation.
Medium Corrosion: All other environments that are not low or high corrosion level.	**Option 1:** G90 + Vapour barrier + Separate ventilation **Option 2:** G90-Duplex or G185 + Separate Ventilation. Apply applicable strength modification factors.
High Corrosion: • High exposure to moisture, organic gases, and chemicals. • Storage of manure and/or silage. • Housing of swine, poultry and cattle.	**Option 1:** G90-Duplex or G185 + Vapour barrier + Separate Ventilation **Option 2:** Stainless steel or G185-Duplex. Apply applicable strength modification factors.

Swimming Pools:

This is one of the most hazardous environments for metal connectors due to continuous exposure to high temperature, high moisture content, and corrosive chemicals such as chlorine, bromine, and other disinfectants. The combination of all these factors can lead to accelerated corrosion and premature structural failure. This environment is so corrosive that all possible preventive measures should be employed to prevent the truss from being exposed to the pool water. These include the use of a vapour barrier and a ventilation system that does not take the air from the pool environment. Due to a mode of structural failure known as stress corrosion cracking (SCC), stainless steel connectors shall not be used over swimming pools (Baddo, Cutler 2004).

WARNING: STRESS CORROSION CRACKING

Stainless steel connectors and fasteners shall not be used in trusses over swimming pools due to stress corrosion cracking. SCC has been known to occur under the following conditions:

- Use of certain grades of stainless steel (grades 304, 316, and others).
- Presence of certain chemicals, including chlorine and bromine.
- Structural members subjected to high tensile stress.
- Near areas of high residual stress; small cracks can rapidly propagate and cause catastrophic failure.

Guideline for Swimming Pools	
Protection	**Comment**
Vapour Barrier + Separate Ventilation + G90-Duplex or G185-Duplex	It is recommended that the truss be designed for wet service condition in case of accidental leakage of vapour into the attic space.

NOTE: *To the best of industry knowledge, the guidelines provided in this technical bulletin can extend the serviceable life of the truss connector plate under the conditions described. However, no warranty or guarantee, other than that offered by the manufacturers of these corrosion-resistant products, is expressed or implied. Corrosive environments may require regular maintenance of these products as part of the standard building maintenance program.*

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