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WHITE PAPER

Comparative Analysis of Stainless and Plated/Coated Carbon Steel

Corrosion and Fastener Material Selection

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The purpose of this paper is to address corrosion in general terms – not to provide a comprehensive reference in regard to all forms of corrosion or a detailed analysis of the strengths and weaknesses of specific alloys. Corrosion of stainless and carbon steel are very different and this paper will provide information regarding general attack or surface corrosion as this is often a primary consideration when selecting fastener material.

Carbon and stainless steel are the most common materials from which fasteners are manufactured and each is available in hundreds of alloys or grades with a wide variety of attributes. Initial cost of a stainless steel component is generally higher than carbon steel though not always. For example - material is a smaller component of cost in a light duty Coiled Pin than it is in a Solid Pin of the same diameter and length. As a result the stainless steel Coiled Pin may be available at equal or lesser cost than the carbon steel Solid Pin. In addition, secondary processes, such as heat treating or plating, often add to the cost of carbon steel parts when they may not be incurred with stainless steel. Cost is meaningless without consideration of value. For example, the manufacturer of a high end outdoor barbecue grill may select stainless steel fasteners capable of resisting corrosion much longer than the product's expected life span. This selection would demonstrate commitment to product integrity, cosmetic appearance, and long life. The 'value' of a fastener that provides maximum quality may offset any associated cost increase. The same manufacturer may opt for lower priced plated steel fasteners for a model sold under a discount brand if the anticipated consumer is more conscious of cost than quality. Both are valid reasons to select one material over the other though the choice of stainless steel requires the customer to consider value as much as cost. Designers must weigh cost, benefit, and risk when choosing the appropriate fastener material.

SPIROL manufactures Coiled Pins, Slotted Pins, Solid Pins, Inserts, Tubular Products, Machined Nuts, Compression Limiters, Shims and Disc Springs to service a wide variety of industries around the globe. Although SPIROL manufactures parts from many materials, both ferrous and non-ferrous, the scope of this paper is limited to ferrous metal products, and more specifically, stainless and carbon steel. SPIROL's ferrous product is manufactured from four primary standard material groups:

- Low Carbon Steel
- High Carbon Steel & Alloys
- Martensitic Chrome Stainless Steel (AISI 410 & 420, EN/DIN 1.4516 & 1.4021)
- Austenitic Nickel Stainless Steel (AISI 302, 304, 305 or EN/DIN 1.4319, 1.4301, 1.4303)

Though carbon and stainless steel are both ferrous metals, meaning they contain iron, their response to corrosive attack is much different. By definition stainless steel must contain at least 10.5% chromium. When exposed to oxygen this alloying element creates a layer of chromium oxide at the surface that quickly stops growing thus becoming 'passive'. This passive layer is continuous, uniform in thickness, insoluble, and non-porous. The passive layer prevents contact between oxygen in the environment and base metal and will self heal if scratched or abraded as long as oxygen remains available. The passive layer is only 10 to 100 atoms thick and as such has no dimensional impact on parts. Though stainless steel can corrode when exposed to some chemical agents under specific conditions, it will not rust by uniform or general attack as does carbon steel. As an alloying element, the chromium is part of a homogenous blend and is deemed safe as it cannot be easily liberated from the alloy. A final note regarding stainless steel is the relative ease with which it is recycled. Stainless steel is 100% recyclable and industry analysts estimate 80-90% of discarded stainless steel is captured for recycling.

Figure 1. Rusting chain demonstrates material loss due to rust or general attack.

Rust occurs in iron and iron alloys such as steel. Rust is a layer of iron oxide created at the surface of a part when exposed to oxygen in the presence of moisture. This layer of iron oxide remains active and continues to convert iron to iron oxide as the outer layers lose integrity and fall away exposing new metal (*See Figure 1*). Iron oxide is also porous allowing it to absorb moisture and elements that may contribute to corrosion thus extending the period of active corrosion with each exposure. To prevent the formation of iron oxide or rust it is necessary to eliminate exposure to oxygen and moisture. For these reasons it can be observed that motor vehicles operated in dry climates will exhibit far less corrosion or rust than the same vehicle operated in a wet environment. In cold wet environments where deicing agents are used on roadways the rate and severity of attack is further increased.

Carbon steel fasteners are generally lower cost than stainless steel and finishes are available that provide excellent corrosion resistance. It should be noted that these finishes do contribute to dimensional growth that must be considered in design. Carbon steel may be protected from corrosion by painting, plating, or coating. Paint is generally not appropriate for fasteners as it tends to be a rack rather than bulk process and is therefore not cost effective. Plating and coating are the predominant methods of preserving carbon steel though some of these processes have fallen out of favor due to their environmental impact. Examples of finishes considered hazardous are cadmium and hexavalent chromates. The past decade has witnessed the maturity of bulk coatings and platings capable of providing excellent corrosion resistance at low cost while satisfying current environmental regulations. Despite these advances, the base metal's susceptibility to rust remains an Achilles heel. The vast majority of platings and coatings are sacrificial, meaning they only provide protection until they are depleted. Once base metal is exposed, it will rust. Some examples of available finishes and coatings are, but are not limited to:

- Zinc phosphate conversion coating – typically followed by application of oil or other rust preventive agent. Secondary application of rust preventive determines corrosion resistance and this ranges from minimal to competitive with platings and other coatings.
- Mechanically applied zinc – minimal risk of hydrogen embrittlement is this finishes primary benefit. Finish can be thicker than electroplate and is not as smooth. Often provided with secondary application of chromate and/or sealers to improve performance.
- Zinc electroplate – typically provided with supplemental trivalent chromate and often a final sealer. These finishes introduce the risk of hydrogen embrittlement for high strength steel; though parts are typically baked in an effort to eliminate this potential problem.
- Zinc nickel electroplate – higher corrosion resistance than traditional zinc electroplate. As with standard zinc electroplate, this process also requires baking of high strength steel to reduce the risk of hydrogen embrittlement.
- Aluminum zinc lamellar coatings – Dip spin process capable of very high corrosion resistance without risk of hydrogen embrittlement.

The most widely accepted method of corrosion testing is the salt spray test. The intent of salt spray testing is to provide a repeatable method by which a material or finish's response to corrosive attack can be evaluated. In theory this also provides a means to compress life cycle testing into a practical period of time. For example, it is not practical for the manufacturer of an exterior door handle to leave a handle outdoors for 15 years to determine if a 15-year warranty is appropriate. It is practical to place the handle in a salt spray booth for a short period of time in an effort to replicate the impact 15 years of corrosive attack may have. It is important to understand that such comparisons may be grossly inaccurate though this method of test remains one of few choices available. No accurate correlation exists between real world conditions and time spent in a salt spray booth. If the door handle manufacturer is concerned with product used in coastal areas, it is critical to understand that potential exposure will only occur intermittently. There may be periods of months with no storms, dry weather, and little if any exposure to corrosive elements. In short, salt spray testing is extreme in relation to the intended use of many fasteners/components and test durations are arbitrarily assigned based upon a designer's best guess regarding correlation with actual conditions. Finally, while many manufacturers now assign salt spray testing to stainless steel product; it is primarily intended for carbon steel parts. Stainless steel is generally tested in a humidity chamber without salt. In instances where exposure to chlorides is of paramount concern, salt spray testing is an acceptable method of test for stainless steel.

Salt spray test requirements generally consist of two simple criteria – the hours it takes for white corrosion to form and subsequently, the hours it takes for red rust (or base metal) attack to begin. Salt concentration, temperature, and time are carefully controlled. The majority of coatings and platings rely upon a layer of nonferrous metal applied over the base metal followed by a chromate dip and depending upon performance requirements, an organic or inorganic sealer. When these finishes fail, they do so opposite the order in which they were applied. Once the corrosive environment breaches the outer sealer and chromate layers it begins to attack the nonferrous metal beneath. At this point white corrosion begins. Nonferrous metals such as zinc, nickel, aluminum, and magnesium do not contain iron and will not 'red rust'. Red rust only becomes visible after the sacrificial metal has been depleted (*See Figure 2*).

An issue with both electro and mechanical plating is the difficulty associated with plating in deep holes and significant crevices. This is of concern on many of the products SPIROL

Figure 2: This Coiled Pin was finished with a light duty zinc plating and subsequent chromate dip. The finish was rated for 48 hours to 'red' corrosion protection. Leaving this item in salt spray for 200 hours has resulted in significant red rust though some zinc and white corrosion remain. Where zinc is present on the surface, the part remains free of red rust despite the severity of attack in adjacent areas.

manufactures such as Coiled and Slotted Pins as well as Tubular Parts. Neither process is capable of achieving proper deposition in the interior of a tube (*See Figures 3 and 4*). Though the process of applying these finishes may deposit chromate and sealer within the interior, it is not possible to achieve 100% coverage with the nonferrous metal (zinc in this case); and this is the most important finish component.

Unlike mechanical and electroplating, coatings applied as a liquid are capable of proper coverage in a part's interior though as previously noted; Coiled Pins present a unique challenge in that the space between coils is unlikely to receive substantial coverage. While this may appear to be a significant concern, it is critical to understand there are many forms of corrosion, and in regard to fasteners, corrosion in these locations is often of little concern. Hundreds of billions of plated fasteners have been utilized successfully over the years despite these issues. If a fastener is fully installed in a host material, it may be largely protected from attack. A good example would be a Compression Limiter sandwiched between two components, protected by a gasket, and capped with a flanged bolt. In terms of galvanic corrosion, the finish need not be uniform to provide protection as it will be sacrificially depleted to protect the base metal as long as current can flow from one to the other. For example, a steel boat hull can be protected by bolting sacrificial zinc anodes in strategic locations – it is not necessary to galvanize or zinc plate the entire vessel. Similarly, zinc on the outer diameter of a Coiled Pin will protect the interior if galvanic corrosion is the mechanism of attack.

Figure 3: This photograph demonstrates the basic geometry of a Coiled Pin – it consists of a number of metal wraps. Platings will not penetrate between the wraps and dip coatings, though capable of covering the interior, will remain ineffective between the pin's wraps.

The advantage of stainless steel remains its ability to resist corrosion without the aid of protective finishes. Corrosion resistance is provided by chromium and this is distributed throughout the alloy. Stainless steel can corrode and fail though it does not rust due to general attack or surface corrosion. Pitting is the most common form of corrosion affecting stainless steel. Pitting may occur when environmental agents or mechanical abrasion/scratching defeat the passive layer under conditions where it cannot spontaneously reform. Local attack can then occur. In salt spray, a water droplet may form on the surface of a part. The water droplet may then concentrate chloride which is highly corrosive. An alternate form of attack generally spread over a larger area is crevice corrosion. This form of attack may occur where there are sharp inside corners or where components touch in a manner that creates potential points of fluid deposition. Good design practices can minimize crevice corrosion, though in many instances it is inherent to the intended function of an application. It is also possible to improve corrosion by moving to other stainless steel alloys. Common methods used to increase resistance to pitting are the addition of molybdenum or higher concentrations

Figure 4: To demonstrate attack between the Coiled Pin's coils (or wraps) of steel, the photograph below was taken after cross-sectioning the pin shown in Figure 3.

of chromium and/or nickel. Increased corrosion resistance typically elevates cost and should therefore only be pursued when necessary.

Of the two stainless steels offered by SPIROL, austenitic (or nickel) stainless steel provides the best corrosion resistance while martensitic (or chrome) stainless is more easily attacked. Nickel stainless steel has two advantages: 1) chromium content is increased from 12% to 18%, and 2) 8% nickel is added to increase resistance to attack from mineral acids. The pairing of chrome and nickel in the proper ratio allows for the creation of an austenitic structure. Martensitic chrome stainless steel may be less corrosion resistant; however, it can be heat treated to achieve higher strength, and the subsequent low rate of work hardening provides excellent fatigue resistance.

Figure 5: Pins prior to test: the top two are low carbon steel coated with zinc lamellar, the bottom two are austenitic 305 SST.

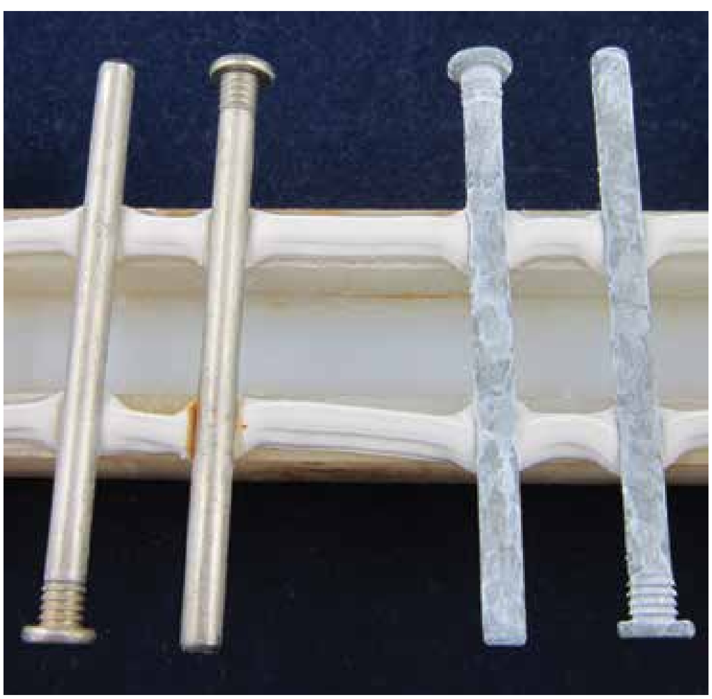

Figure 6: After test, the 305 SST parts remain unchanged (left) while the coated parts (right) exhibit significant white corrosion.

To demonstrate the difference between stainless steel and coated carbon steel two solid pins were manufactured with identical geometry from each material. The stainless steel pin was passivated while the low carbon steel pin was coated with a zinc lamellar product (*See Figure 5*). At 720 hours the coated part has performed well though white corrosion is readily apparent. Once the zinc is depleted, rust will begin. In contrast the austenitic stainless steel pins appear virtually unchanged (*See Figure 6*). A properly passivated 300 series SST pin can provide up to 2,500 hours protection in salt spray.

As previously noted, martensitic stainless steel is less resistant to corrosion than austenitic and it is generally not tested in salt spray for this reason. Both 410 & 420 stainless steel provide good corrosion resistance in normal atmosphere, fresh water, body fluids, and culinary environments as well as mild oxidizing acids such as chromic and nitric acid. The following martensitic stainless steel pins were placed in salt spray and observed for a period of 300 hours. Staining was evident after 48 hours with minor pits beginning to form. After 300 hours pitting was severe and easily captured in the following photographs (*See Figures 7, 8, 9 and 10*).

Figure 7: Pitting with related staining on 420 stainless Slotted Pin.

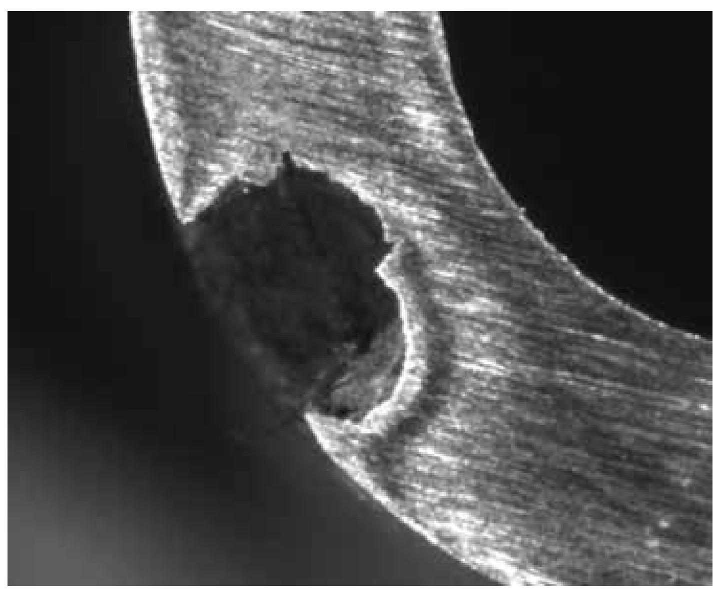

Figure 8: Cross section of pit shown in Figure 7 demonstrating impact on cross-sectional area and reduction in strength.

Figure 9: Pitting with related staining on a 410 stainless steel Solid Pin.

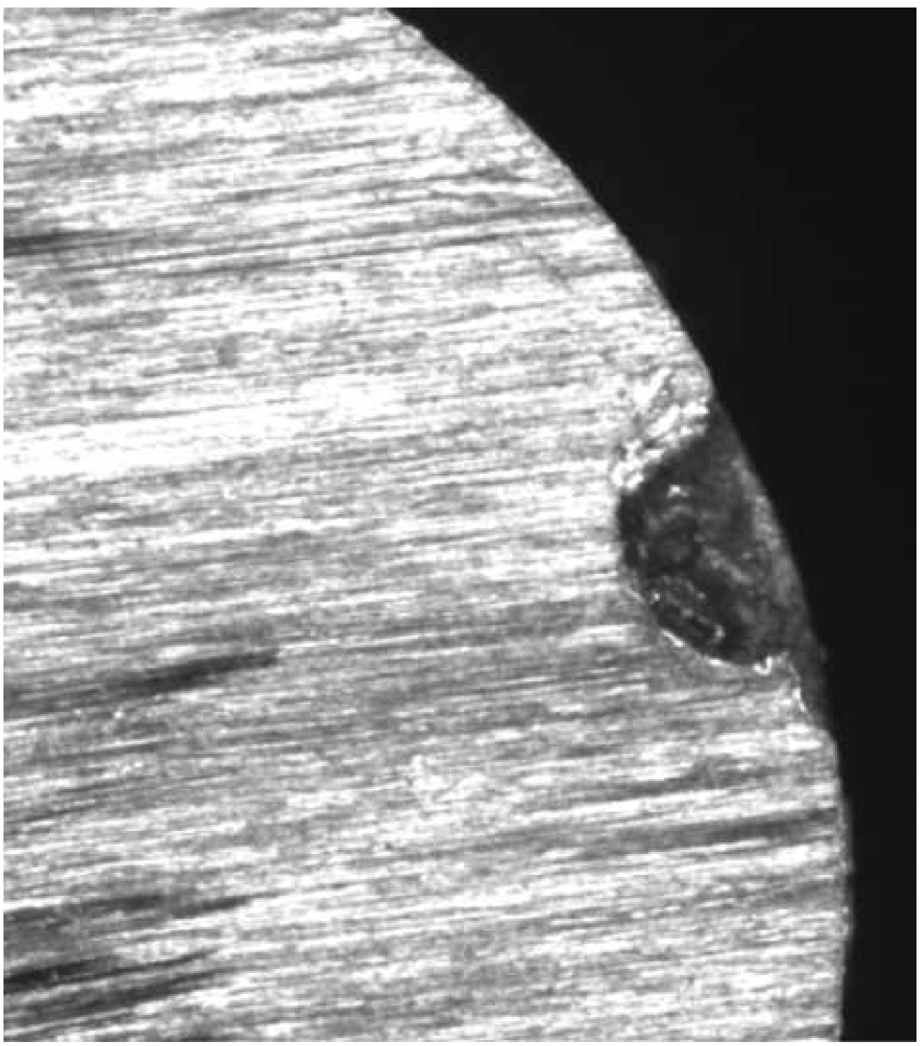

Figure 10: Cross section of pit shown in Figure 9 demonstrating impact on cross-sectional area and reduction in strength.

In summary, though great advances have been made in regard to finishes and coatings available for carbon steel they remain susceptible to corrosion. It is a matter of when, not if, the finish will eventually fail. Stainless steel is often associated with higher cost, although the cost of failure can be much greater. The intended environment and life expectancy of a product must be given adequate consideration and the appropriate material and/or finish selected to ensure success. It is also important to evaluate alternative solutions whenever possible. Reducing material volume by moving from Solid Pins, Alignment Dowels, and other products to Coiled Spring Pins and Tubular Products can significantly reduce weight therefore lowering cost. Carbon steel does not always present the lowest installed cost solution and 'value' should always be considered. Stainless steel is not impervious to attack and the host materials and environment must always be evaluated carefully to ensure the correct grade/type is used.

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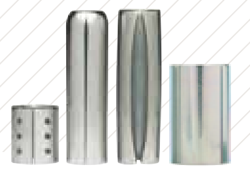
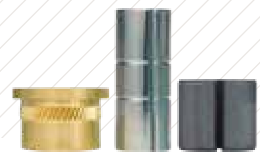
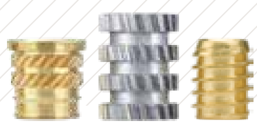


Spacers & Rolled Tubular Components



Compression Limiters



Threaded Inserts for Plastics

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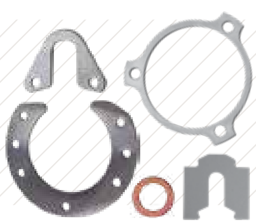

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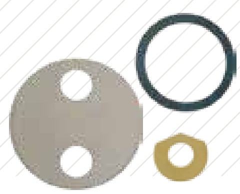

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