Impact of substrate imperfections on the appearance of SilcoTek's coatings

Overview

The cleanliness of a stainless steel substrate surface is crucial to the success of SilcoTek's proprietary CVD process. In general, a "clean" stainless steel surface refers to a surface free of oil, grease, embedded iron particles, and other impurities while maintaining an intact normal oxide film.

SilcoTek uses a state-of-the-art alkaline-based surface preparation process to prepare parts before applying the CVD process. This process has proven to be sufficient in successfully preparing over 98% of the parts received by us on a daily basis (no re-works necessary). However, the small percentage of parts, owing to various imperfections in the substrate materials, present a cleaning/ processing challenge that often results in extended process times and costs. These parts may not come out with perfect appearances like the majority of SilcoTek coated parts, depending on the nature of the imperfections.

The purpose of this white paper is to discuss the various types of surface defects that contribute to an imperfect coating appearance, and how SilcoTek may or may not be able to improve the appearances on these parts.

Most common stainless steel surface defects that are difficult to remove are produced during fabrication. These include embedded iron particles, sulfide inclusions, heat tint, arc strikes, weld spatter, grind marks, scratches and organic contamination. Figure 1 illustrates the common types of surface defects arising during steel fabrication.[1]

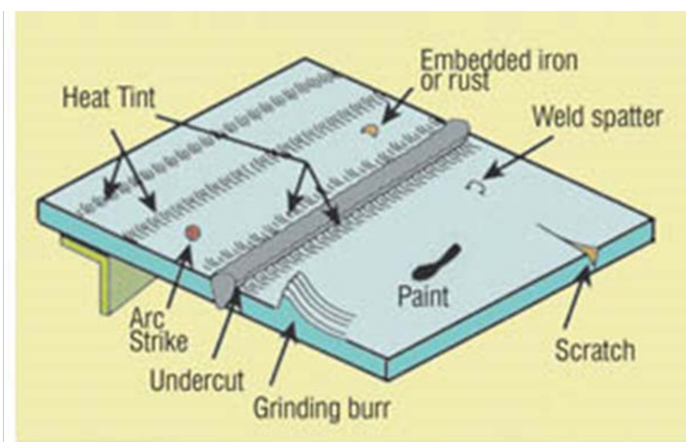

Figure 1. Common types of surface defects arising during steel fabrication.[1]

Embedded iron

Embedded iron is the most common surface defect that arises during fabrication. Iron particles as a result of wear and tear, as well as grinding dust and showers of sparks during carbon steel grinding, can burn into and contaminate a stainless steel surface. Iron is also easily embedded during handling and layout unless stainless steel is protected from contact with wire slings, clamps, layout tables and rolls. Iron embedment is more common in shops that fabricate carbon steel as well as stainless steel parts. This is why stainless steel needs to be protected from carbon steel and must be processed separately from carbon steel.[2]

Iron particles embedded in the stainless steel surface will cause rust when they are exposed to a moist atmosphere, and if not addressed, can produce additional pitting corrosion. If a customer's parts have a high risk of iron embedment, SilcoTek recommends a simple water test or a more sensitive ferroxyl test as described in ASTM A380 to detect and remove embedded iron before sending to SilcoTek for coating. In cases where SilcoTek receives iron embedded parts and detect minor rust spots after our standard surface prep process (as shown in Figure 2 below), we typically employ a mild acid treatment to remove the rust spots before subjecting the parts to our CVD process. For details of SilcoTek's rust-removal process, please refer to our white paper "Removing rust prior to coating".

Figure 2. Rust spots developed on steel surface embedded with iron particles after SilcoTek's cleaning process.

For parts that show severe, large rust areas, where SilcoTek's acid treatment may be less effective, we recommend pickling treatments by the customer as SilcoTek is not equipped to handle such treatments. This requires elimination of the surface layers with embedded defects, including 25 – 40 μm of the substrate metal, and is usually done in a nitric-hydrofluoric acid (HNO_3 – HF) bath.[3]

Sulfide inclusions

Sulfide inclusions, especially manganese sulfide (MnS) inclusions, are believed to be the predominant sites for the initiation of pit corrosion in stainless steel. Manganese is added in the fabrication of stainless steel to make the steel easier to machine, but it was recently discovered that during the cooling of the stainless steel, the MnS inclusions suck chromium atoms from the surrounding area, leaving behind a chromium-deficient region. This Cr-deficient region becomes a weak point for corrosion to initiate (pit), and deteriorates the steel surface.[4]

Such inclusions in stainless steel may be difficult to detect with the naked eye, but show up as dark spots or strings under SEM (scanning electron microscope), as shown in Figure 3 below.[5] These inclusion sites can appear as local abnormalities post SilcoTek's coating deposition, as our thin CVD coating (sub-micron) often highlights substrate imperfections. If not addressed, these inclusion sites can compromise the protective properties offered by SilcoTek coating at these local areas, as these weak points serve as initiation sites for pit corrosion. For best coating appearance and performance, SilcoTek recommends the customer to remove any inclusions prior to sending their parts to us for coating. An acid treatment in nitric acid or a heat treatment of the steel to allow Cr atoms to diffuse from the inclusion back into the surrounding area is recommended to remove inclusion sites.[5]

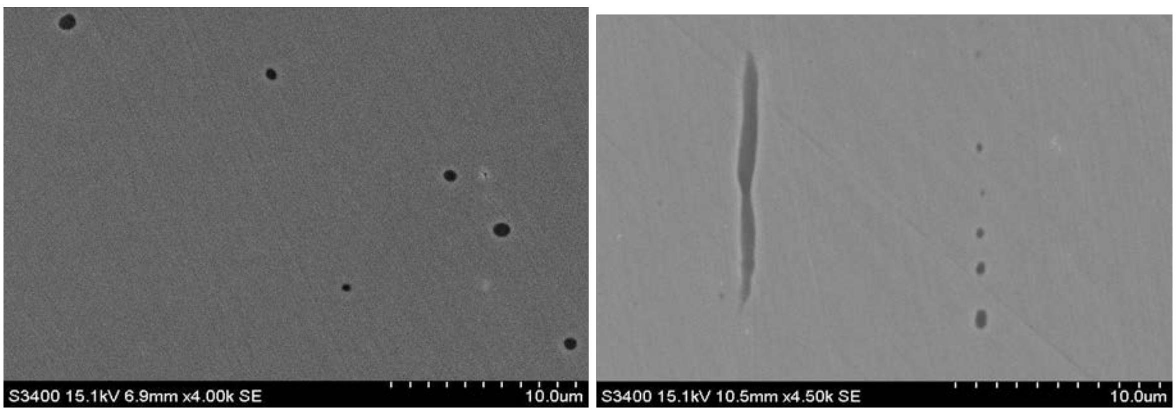

Figure 3. SEM images of typical MnS inclusions in stainless steel surface.[5]

Heat tint, arc strikes and weld spatter

These are all surface defects produced during the steel welding process (illustrated in Figure 4 below), and are easier to avoid through prevention measures than through removal procedures.

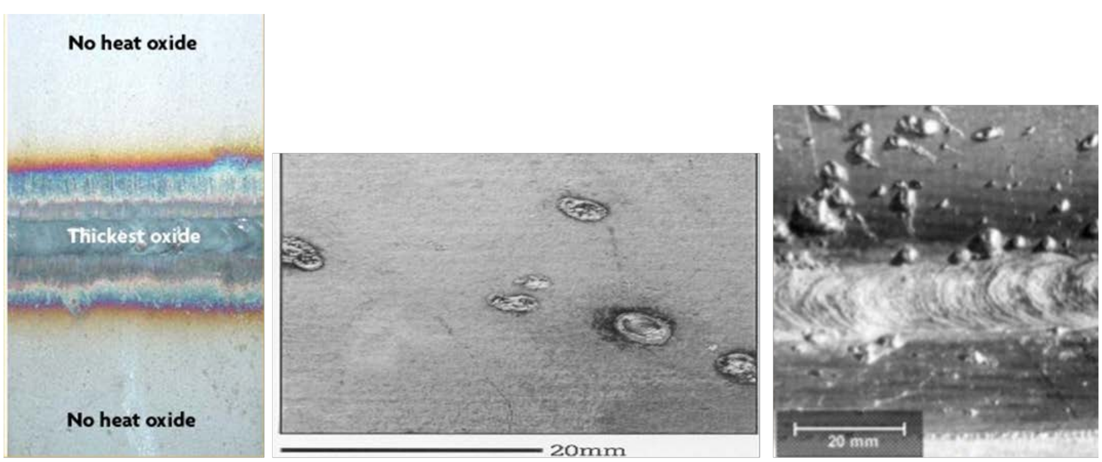

Figure 4. From left to right: heat tint, arc strike, and weld spatter – different surface defects produced during welding.[6,7]

Heat tint (also known as weld discoloration) is a thicker-than-normal chromium oxide film on the surface of the stainless steel. Heat tint films range in color from light brown to black. Figure 4 above shows the typical heat tint on the welded side if stainless steel is welded without inert gas protection.[6] As more chromium is consumed to form the heavier film; the surface beneath the heat tint is depleted in chromium and therefore reduced in its inherent corrosion resistance.

Arc strikes and weld spatter both produce small pinpoint surface defects that penetrate through the surface oxide layer and extend into the substrate steel. They form sites where corrosion can initiate.

These surface defects (heat tint, arc strikes and weld spatter) will show through SilcoTek coatings if they are not addressed, and will compromise the coating's local anti-corrosion properties at the defect sites. It is costly and difficult to completely remove these defects, and the best way to address them is by taking prevention measures, such as employing proper welding techniques, using inert gas shielding during welding, and using anti-spatter paint (and clean it off after welding is completed).[8]

Organic contamination

SilcoTek's alkaline-based surface preparation process is designed to remove any oil, grease and other organic residues on the stainless steel surface prior to the CVD coating is applied. This is a highly effective approach for the majority of the parts received by SilcoTek, but exceptions do exist.

We have experienced difficulties in removing certain glycol-based or Krytox® fluorinated cutting fluids in the past, especially when the oil was left to dry on hot parts before rinsing. Go to our white paper "How clean is clean". Figure 5 shows a part contaminated with organic residues that cannot be completely removed by SilcoTek's pre-deposition procedures. In such cases, SilcoTek will contact the customer to learn more about the handling of the parts prior to our receipt of them, and discuss/ recommend process changes as appropriate.

Figure 5. Organic contamination that cannot be removed by SilcoTek's cleaning process.

If the organic residue is "burnt into" the steel substrate, such as from pyrolysis of lint contamination, they usually show up as black spots/blemishes on the surface. The lint can originate from cotton gloves or cotton gauze used to handle and clean parts prior to welding. Pyrolysis of other hydrocarbons can also create black spots. If this is the case, SilcoTek typically employs a high temperature oxidation process to eliminate the carbon contamination prior to application of the CVD coating.

Scratches and other physical damages

SilcoTek technicians conduct an inspection at the receipt of customer parts. If any scratches or physical damages are noticed on the parts at arrival, we will contact the customer to find out whether the scratched/damaged area is a critical area to their specific applications, and will either continue with processing or return parts to the customer for replacement based on the customer's feedback. An example of scratched part identified by SilcoTek receiving technician is shown below in Figure 6.

Figure 6. Scratches on incoming parts identified at SilcoTek's receipt inspection.

Electropolished surfaces

When a superior surface finish is desired, sometimes a final electro-polishing process is applied to metal parts to achieve aesthetic appearance or optimized corrosion resistance. There are certain pitfalls in the electropolishing process to watch out for, such as an effect referred to as electropolish "frosting". Please refer to our white paper "Coating electropolished surfaces" for detailed discussion on this subject.

Summary

SilcoTek receives and processes hundreds of customer parts daily, and these parts may have seen hundreds of different handling techniques and surface treatments before they reach us. We strive to coat each and every single piece consistently and beautifully every time, in our commitment of plus 1 service to all our customers. However, various imperfections present in the substrate materials as discussed above may contribute to an imperfect appearance on a small percentage of the parts. When this happens, SilcoTek will reach out and collaborate with our customers to find a solution together. It is always our goal to provide the best quality coating and service to every customer every time, with zero disappointments.

References

1) http://www.assda.asn.au/technical-info/surface-finishes/stainless-fabrication-common-traps-to-avoid.
2) N. W. Buijs, “How do you remove and prevent flash rust on stainless steel?” Stainless Steel World November 2008 issue.
3) A. H. Tuthill and R. E. Avery, “Specifying stainless steel surface treatments”, Advanced Materials & Processes **1992**, 142 (6), 1.
4) M. P. Ryan, D. E. Williams, R. J. Chater, B. M. Hutton & D. S. McPhail, “Why stainless steel corrodes”, Nature **2002**, 415, 770.
5) A. W. Gjonnes, “Effect of sulfide inclusions in austenitic stainless steel on the initiation of pitting in base metal and heat affected zone after welding”, Master thesis **2012**.
6) http://www.foodprocessing.com.au/articles/40976-Purge-welding-stainless-steel-for-cleanability-and-corrosion-resistance.
7) D. J. Helliwell, “Defects and discontinuities”, ESC defects training QA/QC.
8) A. H. Tuthill, “Stainless steel: surface cleanliness”, Pharmaceutical Engineering **1994**, 14 (6).