FABRICATION AND POST-FABRICATION CLEANUP OF STAINLESS STEELS

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The surface condition of stainless steels is critical both where the product must not be contaminated, *e.g.*, pharmaceutical, food and nuclear plants; and where the stainless must resist an aggressive environment, such as in chemical-processing plants. Although the highly protective chromium oxide film that makes stainless steel "stainless" is tenacious, durable and self-healing, in the presence of oxygen, this film can become damaged. In fact, fabrication and post-fabrication cleanup practices can disturb this film in a variety of ways. *For example*, Fig. 1 shows corrosion that occurred at several points along a deep scratch in a stainless vessel (in the areas marked 28 and 29).

Fig. 1. *A deep scratch made during fabrication served as an initiation site for corrosion in this vessel*

However, as we will show, most of these problems can be overcome. First, we will consider contamination by iron and explain how to minimize and detect it.

A common manner in which iron is embedded in the surface during fabrication is shown in Fig. 2 of piping at a coastal plant. The welder used a carbon steel brush to clean the weld leaving both Heat-Affected Zones (HAZ) severely contaminated from the iron embedded in the surface by wire brush cleaning with steel rather than stainless steel wire brushes. The other rust spots resulted from failure to protect the stainless steel piping from steel construction work undertaken after the piping was installed. This type of iron contamination is easily prevented, but does require some care and planning during the construction phase.

Fig. 2. *Iron embedded by a carbon steel wire brush and construction work in the same area has initiated pitting corrosion on stainless steel pipe.*

AVOIDING IRON CONTAMINATION

Sometimes, new stainless-steel tanks or vessels rust shortly after delivery from a fabricator. This is due to iron embedded in the surface during fabrication. Such iron corrodes in moist air or when wetted,

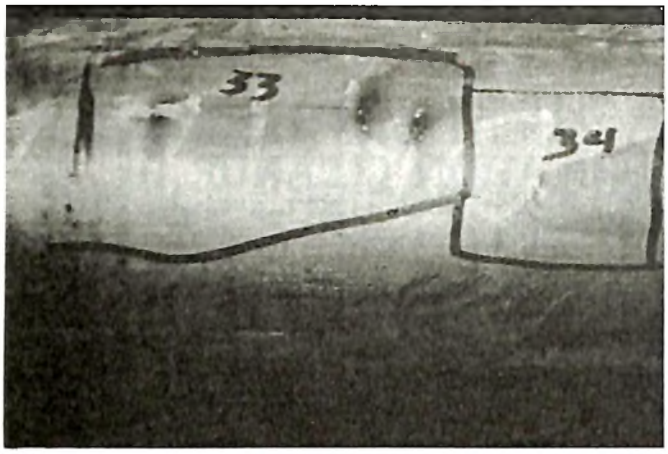

Fig. 3. Pitting Corrosion occurred where crayon markings were made, and not later removed, on a stainless-steel vessel

leaving telltale rust streaks. In addition to being unsightly as they corrode, the larger particles of embedded iron initiate crevice corrosion in the underlying stainless steel. In the pharmaceutical, food, and other processing industries in which stainless is used primarily to prevent contamination of the product, embedded iron cannot be tolerated. Minimizing embedded iron includes measures taken during:

1. *Procurement*—Sheet, strip and pipe can be procured clean, with a good surface finish, *e.g.*, 2B [an American Iron and Steel Institute standard finish] or equivalent. Plate is normally Hot Rolled, Annealed and Pickled (HRAP), and is not furnished to a 2B finish.

   While the mill may have properly cleaned a plate surface, there are still wide variations with respect to slivers, inclusions and roughness. When the surface of plate is considered important, the required condition should be fully specified during procurement.

2. *Shipment and storage*—Normally, stainless steel is received at the fabricating shop in good condition. When cleanliness is very important, sheet and plate can be ordered with a protective adhesive-paper that can be left on during storage and much of fabrication. Use of this paper helps to reduce the amount of final cleaning needed, especially, in shops that fabricate carbon steel as well as stainless steel. Pipe can be ordered with protective end-covers, which are helpful when the pipe is stored outdoors.

   Sheet and plate should always be stored upright in racks, never horizontally on the floor. Foot traffic and workers dragging plates over each other are prime causes of damaging scratches and embedded iron.

3. *Handling*—Here, a little care goes a long way. Using cardboard or plastic sheets on carbon-steel layout and cutting tables, forming-roll aprons, and rollout benches minimizes iron embedment. Also, to prevent such contamination, use plastic, wood or even aluminum guards on slings, hooks and forks of forklift trucks.

4. *Design*—The vessel (or other piece of equipment) or pipe must be free-draining. Interiors should be as clean and free of attachments as possible. When internal attachments are needed, they should interfere as little as possible with free drainage. Bottom connections protruding into vessels even slightly allow puddles and debris to collect on the bottom, the area needing cleaning most. Recessed connections allow total drainage and cleaning .

Special measures are critical for large flat-bottom tanks for which the bottom is used as a work area during construction. Debris collects there, and foot traffic grinds the debris into the surface.

A simple and effective way to greatly reduce the amount of debris that could be ground into the surface is, at the end of every day, to use a hose to flush out the bottom. Employing a slight slope toward the drain

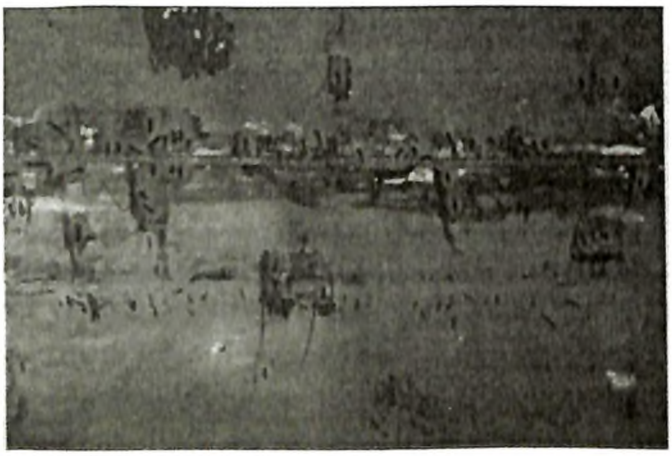

Fig. 4. Weld spatter resulted in corrosion; weld repairs were required after the affected spots were ground out

and recessing the drains are essential, so that flushing will remove, not just spread, the accumulated grit and dirt. Sometimes, a slatted-wood floor should be installed to reduce foot traffic on the stainless-steel bottom.

DETECTING EMBEDDED IRON

The simplest test for free, embedded iron is washing down with clean water, draining completely and waiting 24 hours. Then, inspect for rust streaks on the surface. This is a minimum-type of test that any fabricating shop can conduct. To ensure against rust streaked units, specify use of the water test in procurement documents.

A more-sensitive indication of embedded iron is obtained *via* the ferroxyl test for free iron. The test solution is prepared by mixing the following ingredients:

Ingredient	%	Amount Volume or weight
Distilled water	94	1,000 cm^3
Nitric acid, 60–67%	3	30 cm^3
Potassium ferricyanide	3	30 g

The solution is best applied using a one-quart spray applicator, the type that applies bleach to laundry. Iron contamination is indicated by the appearance of a blue color after a few minutes. The depth of color roughly indicates the degree of contamination. The solution should be removed after a few minutes with a water spray or a damp cloth. If the reagent is difficult to remove, apply household vinegar.

The ferroxyl test is not only sensitive, it can be easily performed in the field, as well as in the shop. Personnel can be trained in only a few hours in administering it. This test is generally required for stainless-steel equipment used in pharmaceutical, food, nuclear, etc., plants, as well as for equipment used to process chemicals.

An excellent basic guide to these tests and other measures to protect stainless is ASTM's (Philadelphia) ASTM A380, "Standard Recommended Practice for Cleaning and Descaling Stainless Steel Parts."

Embedded iron is removed by pickling. This process will be discussed later on, after discussion of degreasing, which is done first.

PREVENTING ORGANIC CONTAMINATION

In aggressive environments, organic contaminants on stainless may foster crevice corrosion. Such contaminants include grease, oil, crayon (construction) markings, paint, adhesive tape, sediment and other sticky deposits. Fig. 3 shows three pits (in the area marked 33) on a stainless-steel vessel. The pits formed where crayon markings, made during an outage, were not removed from the surface before the vessel was returned to service.

Although crevice corrosion is generally not a problem in mild environments, such as fresh water, organic contamination must be removed so that measures taken to remove embedded iron will be effective. Because little can be done during fabrication to reduce organic contamination, the fabricator must do this during final cleanup.

Detection—The usual method is visual inspection. Although thin oil-films may be difficult to see, other organic contamination is not.

Removal—Degreasing, using a nonchlorinated solvent, is effective. The water-break test is a simple way to judge the effectiveness of degreasing: A thin sheet of water (applied by a hose) directed on a vessel wall will "break" around any surface contamination. Degreasing should be redone until the water stops breaking.

It is, of course, essential that only non chlorinated solvents be used. If a proprietary degreasing solvent is chosen, test it to be certain that it does not contain chlorides. Residual chlorides can remain in crevices and give rise to chloride stress-corrosion cracking in stainless steels.

REMOVING EMBEDDED IRON

Pickling, which is carried out after degreasing, is the most effective method for removing embedded iron. Unless first degreased, surface oil, grease and other organic materials may not become wet during pickling, and, thus, iron will not be removed from the

Fig. 5. This vessel corroded due to heat tint (top) and a contaminated surface that was improperly cleaned (bottom)

surfaces beneath oil, grease or other organic contamination.

In pickling, the surface layer (< 1 mil) is removed by corrosion, normally in a nitric/hydrofluoric acid bath at 120°F. Pickling not only removes embedded iron and other metallic contamination, it leaves the surface bright and clean, and in its most resistant condition, *i.e.* passive. Since pickling is controlled corrosion, low-carbon or stabilized grades of stainless are preferred, since the process may initiate intergranular corrosion in the HAZ of regular unstabilized grades.

Passivation is carried out in nitric acid. Unlike pickling, which is controlled corrosion of the surface, nitric acid does not corrode stainless or remove the surface layer. Nitric acid passivation simply thickens the chromium oxide film. Consequently, passivation does very little to reduce metallic surface contamination. Passivation is most useful on machined surfaces especially those where the cross section has been exposed by machining. Although passivation in nitric acid is sometimes called for after pickling, this is somewhat redundant as a properly pickled surface is already passivated.

Fig. 6. A weld on the opposite side of this vessel resulted in corrosion in the heat-tinted area

Small objects are best pickled by immersion. Piping, field-erected tanks and vessels that are too large to immerse can be treated by circulating the pickling solution through them. Typically, chemical-cleaning contractors are hired to do this.

During fabrication, when ferroxyl testing shows only spotty patches of iron, these can be removed by local application of nitric/hydrofluoric acid paste. For large tanks, filling to about 6 in. to pickle the bottom, and locally removing embedded iron on side-walls is often a practical alternative to circulating pickling solution throughout them.

Methods other than pickling can be used to clean a surface, but not all of them yield good results:

- *Grit blasting*—Grit blasting is generally unsatisfactory because grit is seldom clean, and even if it is initially, it soon becomes contaminated with abraded material. Grit blasting leaves a rough profile that makes the stainless steel prone to crevice corrosion, whether or not the surface is free of iron. Thus, grit blasting should be avoided.
- *Sand blasting*—This method is generally unsatisfactory. However, for a severely contaminated surface, sand blasting can be used as a last resort. New, clean sand will remove debris and heavy iron-contamination from the surface. But avoid using sand blasting, if possible.
- *Glass-bead blasting*—Good results have been obtained with clean, glass beads. Before applying this method, a test should be made to determine that it will remove the surface contamination. Also, periodically test to see how much reuse of the beads can be tolerated before they begin to recontaminate the surface. (Walnut shells have also performed well.)

- *Grinding*—Grinding with clean grinding wheels or clean continuous-belt grinding belts tends to overheat the surface layers to the point where the corrosion resistance of the surface is degraded. Grinding is best limited to clean abrasive discs and flapper wheels which do not disturb the surface as much as grinding wheels or continuous-belt grinders.
- *Electropolishing*—One of the most effective methods of cleaning stainless steel fabrications is electropolishing. In electropolishing, the surface to be cleaned is made the anode and direct current is used to effect a controlled corrosion of the surface. A number of electrolytes are used, one being oxalic acid. Electropolishing may be done locally to remove heat tint from the heat-affected zones of welds. Large fabrications such as the large head boxes of paper machines are also electropolished. In addition to removing surface contamination, electropolishing also tends to smooth the surface as the ridges corrode faster than the valleys.

PREVENTING CONTAMINATION DURING WELDING

During welding, the surface of the stainless can be affected by slag from coated electrodes, heat tint, arc strikes, welding stop points, and weld spatter. These all have started corrosion in aggressive environments that normally do not attack the stainless surface .

With chlorides and other aggressive chemicals, corrosion initionation sites can also be created by heavy grinding after welding, welding of attachments on the outside surfaces, rough machining, shearing and other operations that roughen the surface. In mild environments, e.g., fresh water, stainless steel can normally tolerate such surface imperfections.

Arc strikes damage the stainless steel's protective film and create crevice-like imperfections in or near the HAZ. Weld stop points create pinpoint defects in the weld metal. Arc strikes and weld stop points are more damaging than embedded iron, since they occur where the protective film has been somewhat weakened by the heat of welding.

Weld stop defects can readily be avoided by using runout tabs (extensions at the beginning and end of a weld), and by beginning just ahead of the stop point, and welding over each intermediate stop point. Arc strikes are not eliminated as easily. Initially, the arc can be struck on the runout tab. It can also be struck on the weld metal when the filler metal will tolerate this. When the filler will not tolerate arc strikes, the arc must be struck alongside it, in or near the HAZ.

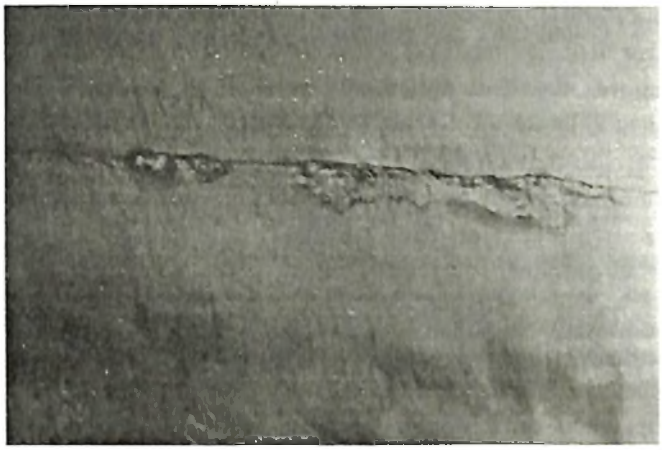

Fig. 7. Corrosion initiated because slag was not completely removed from around a weld made with a coated electrode

Weld spatter creates a tiny weld where the molten slug of metal touches and adheres to the surface. The protective film is penetrated and tiny cervices are created where the film is weakened the most. In Fig. 4, repair welds were required after the spots of weld spatter were ground out and the piece rewelded. Such problems can easily be eliminated by applying a commercial spatter-prevention paste to either side of the joint to be welded. Nearly all welding houses stock such pastes. The paste and spatter are washed off during cleanup.

Heat tint, as several investigators have shown, weakens the protective film beneath it. This weakening is greater for some degrees of heating than for others, as indicated by the amount of color change.

Fig. 5 shows corrosion initiated by heat tint. The wide spread spotty corrosion outside of the heat-tinted area is due to surface contamination not fully removed after fabrication. In Fig. 6, corrosion in the heat-tinted area resulted from a weld made on the outside of a structure.

Actually, there is considerable controversy regarding removal of heat tint. In some cases, the cost can be substantial. Advocates agree that the need to remove the tint is greatest in environments that are so aggressive that the stainless steel approaches the useful limits of its ability to resist corrosion. Also, corrosion engineers agree that the tint need not be removed when the stainless offers a good margin of resistance over that required for the particular environment.

There is, however, general agreement that heat tint should be removed from the surface of fabricated stainless steels for high-purity water, pharmaceutical, brewery and biopro cessing services where it is necessary to minimize iron or other ionic input into the high-purity process fluid.

There is much controversy about which removal methods are practical.

When size permits, pickling by immersion in nitric/hydrofluoric acids is the simplest and preferred way to remove heat tint, as well as other surface imperfections. For large or field-fabricated vessels, a pickling paste can be applied to heat-tinted areas. However, such application can initiate corrosion of the stainless substrate, unless the paste is promptly removed, according to the manufacturer's directions. Pickling paste applied near the end of one shift, and left on to be removed by the next one—or on the next day—will initiate considerable corrosion of the stainless steel.

The author has had excellent results in removing heat tint by local electropolishing (whereby a surface is made an anode). This can be done with a copper grounding-strip, a nylon-mesh wrap, and a mild acid, such as 10% oxalic, using a d.c. welding machine as the current source. The method requires only a short dwell time for removal and avoids the danger of overpickling and consequent substrate corrosion.

Glass-bead blasting, using clean beads, is also an excellent way to remove local heat tint. But do not over-roughen the surface; prevent this by selecting the proper bead size.

Slag from use of coated electrodes is difficult to remove completely. Small slag particles resist cleaning and particularly remain where there is a slight undercut or other irregularity. Slag particles create crevices and must be removed. Fig. 7 shows corrosion that initiated around slag that was not completely cleaned from the side of a stainless-steel weld made with a coated electrode.

When coated electrodes are used, wire brushing is needed, but this requires careful control. Carbon steel and Series 400 stainless steel make stiff wires, but severely contaminate the surface and should never be used—please refer to Fig. 2. Series 300 wire brushes are the only ones to use on stainless steel. Even so, metal transfer from Types 302 and 304 stainlesses to the surface of more highly alloyed stainlesses occurs during brushing. This leaves the surface contaminated with a less corrosion resistant material. For critical service, follow brushing with local pickling or glass-bead blasting. (Shops with nitric/hydrofluoric acid pickling baths can easily check their wire brushes. Carbon steel and Series 400 brushes corrode easily after immersion in the bath; Series 300 come out bright.)

Grinding is used commonly to remove slag, arc strikes, heat tint and other surface imperfections. Unfortunately, grinding wheels and continuous-belt grinders overheat the surface, substantially reducing corrosion resistance. Thus, such devices should be avoided, as previously discussed.

Abrasive disks and flapper wheels are not as harmful, and have produced good results when carefully used. Disks must be clean and, therefore, frequently replaced. The best method is to limit the use of coarser disks and employ the finer grades to smooth over the surface.

SPECIFYING TREATMENT PROCESSES

Degreasing and removing embedded iron from stainless steel maintain its resistance in air, water and other environments. These operations are good commercial practice and are generally expected to be done, even when not called for during procurement.

The use of post-fabrication steps to eliminate postweld problems varies. For high-purity water and aggressive chemicals, such cleanup practice must be spelled out in detail during procurement. For fresh water little more than degreasing and removing embedded iron are needed. Overall, defining the necessary post-fabrication processes during procurement will avoid cost overruns and possible poor service performance.

ACKNOWLEDGEMENT

This article is based on one that originally appeared in *Chemical Engineering,* September 29, 1986.

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(Contd. from Page 17)

STAINLESS STEEL WELDING & APPLICATIONS

Dissimilar Welding

Dissimilar welds are often required in the construction of process equipment. The expensive stainless materials are only needed in the areas exposed to corrosive conditions and less expensive carbon-manganese steels can be used for supporting structures and external reinforcements. When it comes to joining stainless steels to unalloyed steel, the main requirement is that the weldmetal should withstand the dilution between 30-50%, depending on the process used, without cracking. AISI types 309, 309Mo and 312 weldmetals are well established for joining mild or low alloyed steels to stainless steels. For high temperature applications, NiCrFe weldmetals are used for joining low carbon stainless steel to Cr-Mo steels. The Ni based weld metal prevents carbon migration from the creep resistant CrMo steels.

Cladding

Cladding with stainless steels is often carried out in the construction of heavy walled components for the process industry. The base materials are often carbon-manganese steels or low alloyed creep resistant chromium steels, like those used for petrochemical process reactors. Strip cladding using submerged arc welding (SAW) or electroslag welding (ESW) is excellent for large areas due to the high productivity and the low dilution of the base material. In the case of SAW the first layer on carbon steel must be "over -alloyed" *e.g.,* 309L or 309LMo types, to avoid brittle diluted weldmetals. Two layers of the required type of cladding are then usually overlaid. Due to the low dilution with ESW, it is possible to weld directly with the required type such as 316L or 347, on carbon steels. One typical application is the strip cladding of a hydro-cracker in CrMo steel. Because of heat treatment, it is necessary to control the ferrite content in the stainless steel cladding with FN between 3-8 or max. 10.

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