



the Conduit

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HOW TO SPOT HYDROGEN DAMAGE

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By: Catherine Noble Senior Engineer

Hydrogen damage is a specialized form of under-deposit corrosion sometimes found in boiler tubes. During operation, deposit builds up on the tube surface, and when the tube metal corrodes, hydrogen is produced. Hydrogen evolves from the corrosion reaction and, when trapped between heavy deposit and the tube wall, diffuses more easily into the tube metal than through the deposit. Hydrogen atoms then combine with carbon in the steel and form methane gas. Methane collects at the grain boundaries and builds pressure, eventually forming fissures along the grain boundaries. Once enough fissures are formed, they begin to link, severely weakening the tube wall, and eventually the tube ruptures due to the normal working pressure.

This damage mechanism is particularly insidious because there is no external visible damage to the tube in the form of bulging or cracking prior to the failure.

However, the resulting failure has definitive characteristics including:

- thick-lipped rupture,
- window-type rupture,
- numerous fissures and micro-cracks in the tube material at the rupture edges and along the internal surface, and
- severe wastage with internal deposit build-up around the rupture and further down the tube, typically on the hot side of the tube.

A tube with suspected hydrogen damage can also be examined in the laboratory to confirm hydrogen damage by the use of a specific etch on the tube cross section.

The case study below is an excellent example of a tube failure from hydrogen damage and the laboratory etch test confirmation of the damage.

Background

A boiler tripped and was found to have a failed waterwall tube (Figure 1). Plant personnel reported that during tube removal they observed

corrosion on the inside of the tube for approximately two feet below the failure and twenty feet above the failure. The tubes were specified as ASTM A210 with a minimum wall thickness (MWT) of 0.280 inches.



Figure 1. Failed waterwall tube.

Visual Examination

When received in the laboratory, the failure was observed to consist of a long, window-type rupture on the hot side of the tube that was about 11 inches long. The rupture window edges were thick-lipped with significant pitting observed on the internal surface (Figure 2).

Internal Examination

The tube was split longitudinally to facilitate examination of the internal



Figure 2. Thick lipped edges of rupture window.

surface (Figure 3 and Figure 4). Significant pitting with heavy deposits was noted on the failure side (furnace side) of the tube. Slight pitting and deposits were noted on the cold side of the tube section.

Tube Properties

The tube properties were checked and the chemical composition and hardness met the requirements of ASTM A210, Grade A-1 carbon steel boiler tubing. The microstructure remote from the failure was typical for this material with no defects or deficiencies noted.



Figure 3a. Pitting on internal surface at failure.



Figure 3b. Pitting on internal surface adjacent to failure.

Deposit Analysis

The internal deposits remote from the failure consisted primarily of iron-oxide. Trace amounts of silica (detected as silicon) were also noted. These results are fairly typical for waterwall internal deposits, and they were examined from within a pit. It was assumed that the corrosive species that caused the pitting was washed away with escaping steam during the failure event, or there had been a prior upset which exposed the tubes to a corrosive environment, and subsequent operation removed the corrosive species.

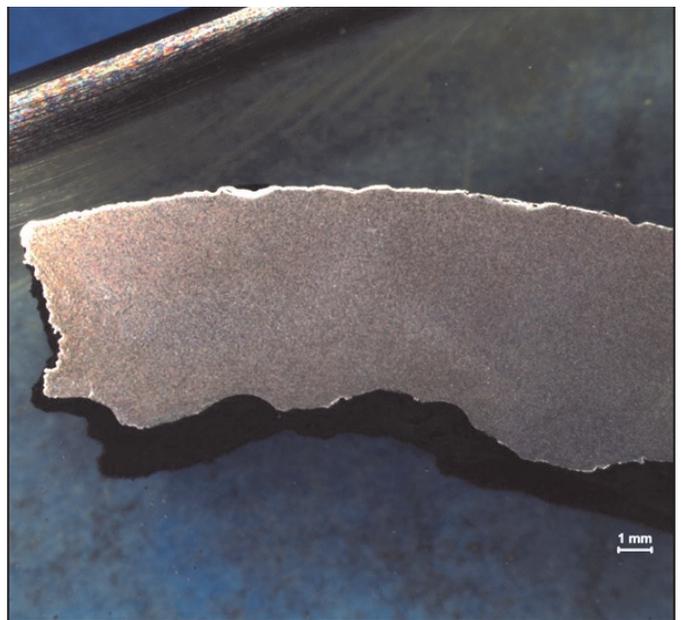
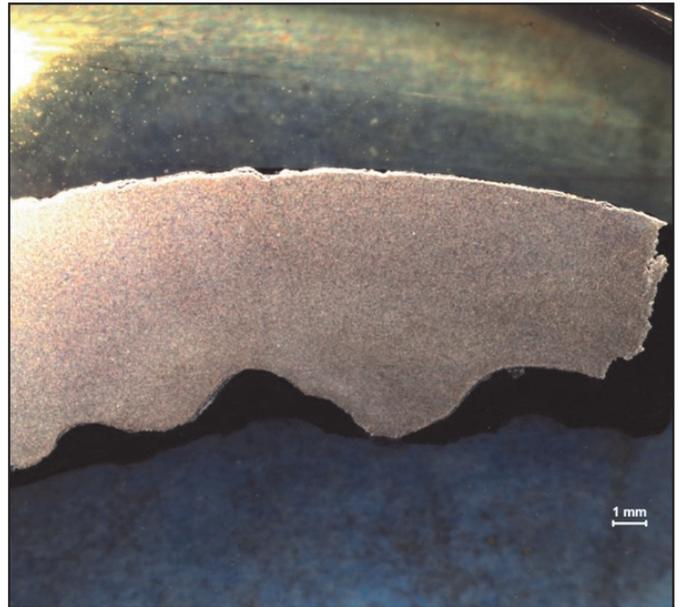


Figure 4. Blunt rupture tips and internal wastage.

Metallographic Examination

The rupture tips were blunt with minimal evidence of plastic deformation (Figure 4). Significant wastage was noted on the internal surface. Gross internal wastage was also noted on the remote cross section in the same location as the rupture. Most of the corroded area remote from the failure was heavily lined with oxide.

At higher magnification, a significant number of fissures and micro-cracks were noted along the rupture edges and the internal surface near the rupture (Figure 5). These fissures and micro-cracks are typical of hydrogen damage. There was also some decarburization at the rupture, which is another feature of hydrogen damage.

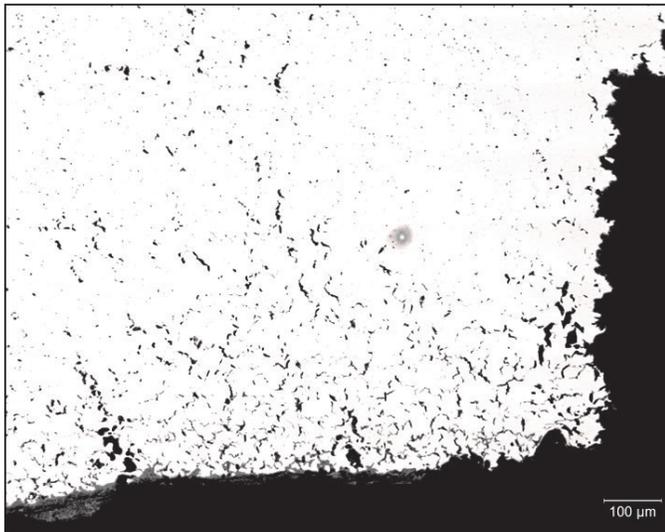


Figure 5. Fissures in the microstructure caused by hydrogen damage.

Slightly away from the failure, the typical microstructure of the tube consisted of pearlite in a ferrite matrix, with some fissures at the grain boundaries (Figure 6).

Hydrogen Damage Test

Because several characteristics of hydrogen damage were noted during the examination, a ring section in a damaged area was used for a hydrogen damage test. In order to confirm hydrogen damage, the tube cross section was macro-etched with 50% hydrochloric acid for one to two minutes.

The test was positive for hydrogen damage in a localized area (Figure 7). The tube metal turned dark around the area of wastage, and partially through the tube wall.

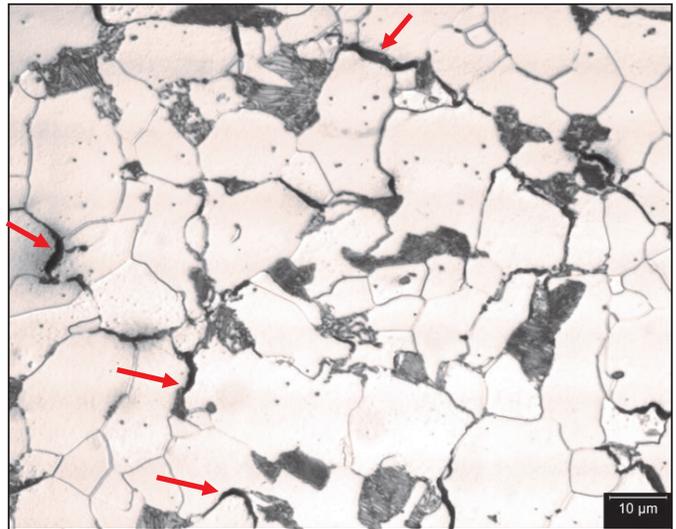


Figure 6. Microstructure slightly away from the failure consisted of pearlite in a ferrite matrix with some fissures at the grain boundaries.

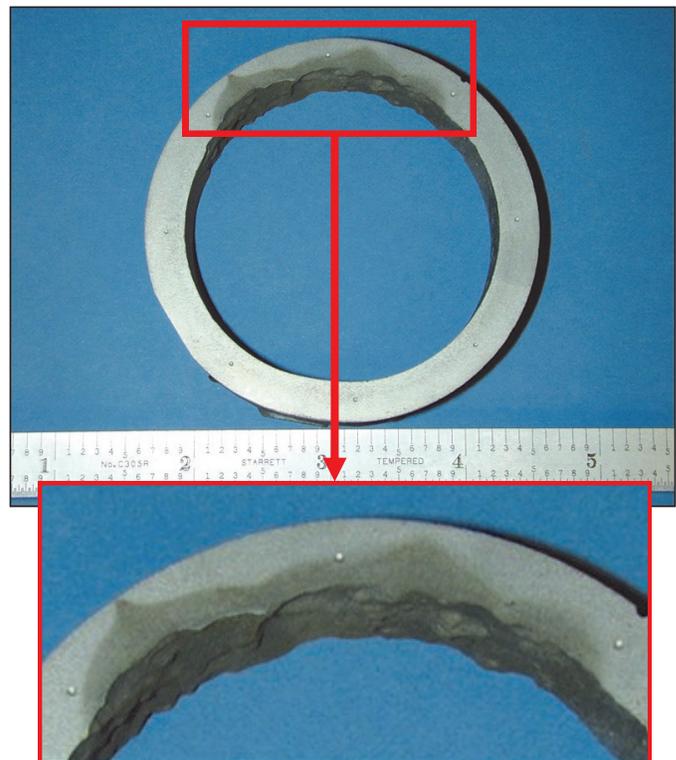


Figure 7. Positive hydrogen damage test.

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Metallurgical Aspects of Welding Stellite 12 and 316L Stainless Steel

By: Oscar Quintero

Metallurgical and Materials Engineer

INTRODUCTION

Welding a Stellite overlay on stainless steel can be a daunting task and cause various issues if not welded properly. Cracking along the weld line, hydrogen induced cracking, and porosity, among other problems have been reported on welding 316L steel with Stellite overlay. This article will try to address issues such as lack of fusion and porosity encountered when welding Stellite 12 to 316L stainless steel, and mitigation strategies that can be applied to reduce problems.

FUSION/DILUTION ISSUES

Dilution is defined as the change in chemical composition of a welding filler metal (in this case the Stellite) caused by the mixture of the base metal (or previous welds if several weld passes were made) in the weld bead.

The dilution between both materials is very important. Too little dilution and you could have a stress riser at the fusion line that can potentially lead to failure. Too much dilution and you could lose the wear properties associated with the overlay surface. The lack of fusion (too little dilution) can cause a hardness (or microhardness) gap creating stress risers. Stress risers are areas in which localized stresses are highly concentrated. If these stresses exceed the materials strength, a crack may result and potential failure may occur.

A microhardness profile between the base material and the stellite overlay can give very helpful information about the dilution area. A step in the hardness profile indicates that the diffusion/dilution between both

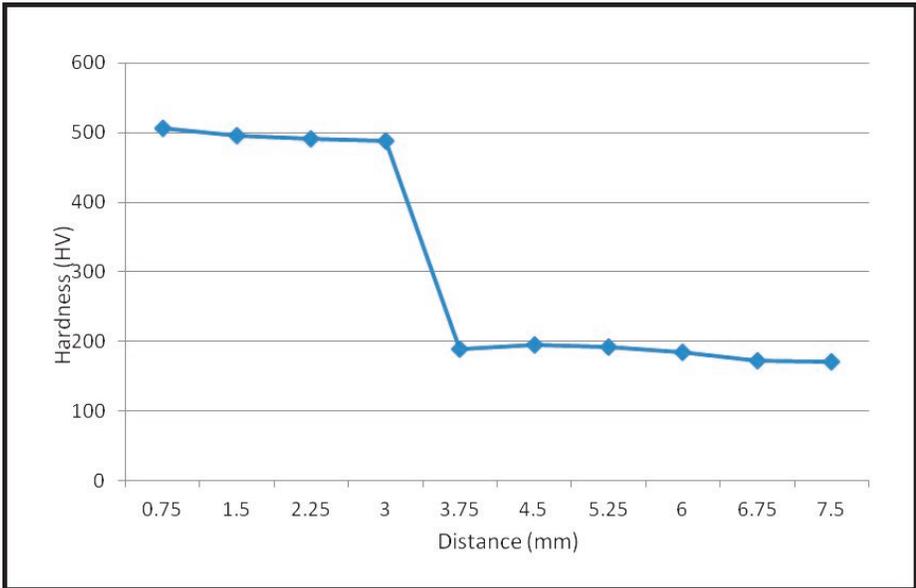
materials is very poor. The microhardness measurements at the overlay would indicate very high hardness values (usually in the Rockwell C scale) while the base material would have readings in the Rockwell B scale. A step function would also indicate a lack of dilution that is usually harmful to the mechanical properties, such as tensile strength and fracture toughness, of the component in question.

Figure 1 shows the results of microhardness testing in the fusion area between Stellite 12 and 316L stainless steel. As it can be seen, a steep microhardness drop was noted between the base metal and the hardened surface at a distance of approximately 3.5 mm. The hardness drop was close to 300 points in the Vickers scale, which converts to approximately 30 HRC. In addition, the dilution between the overlay (Stellite 12) and the base metal is almost non-existent, as seen in the energy dispersive X-ray spectroscopy map of the fusion line (Figure 2). This suggests that in this particular case, there was an issue in the welding process which caused this low dilution, such as a low temperature prohibiting the base metal and hardface layer from mixing properly.

GAS POROSITY

Porosity, or holes within the weld metal, usually occurs due to the absorption of gases or a chemical reaction. This happens when a metal susceptible to porosity dissolves large amounts of gas contaminants into the molten weld pool that are entrapped when the weld solidifies. Sources of porosity are usually contaminants such as moisture, oil, paint, rust, oxygen, and nitrogen in the air. Heat from the welding arc also decomposes such contaminants into hydrogen and other gases.

Another factor that contributes to porosity when welding is the cooling rate. When cooling rates are fast,



Hardness (HV)	Distance (mm)
507	0.75
496	1.5
491	2.25
488	3
189	3.75
195	4.5
192	5.25
184	6
172	6.75
170	7.5

Figure 1. Microhardness profile of a stellite overlay on 316L stainless steel.

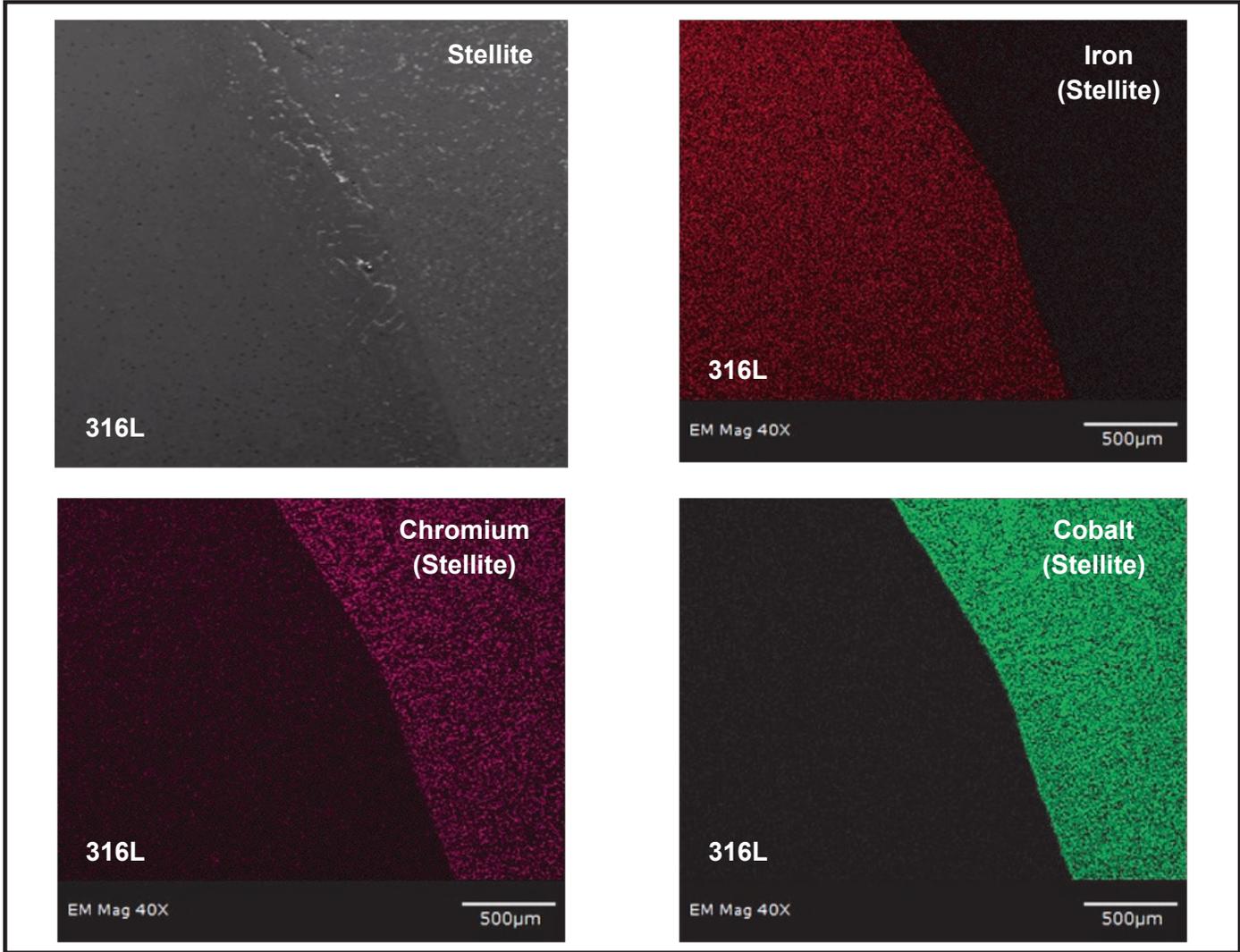
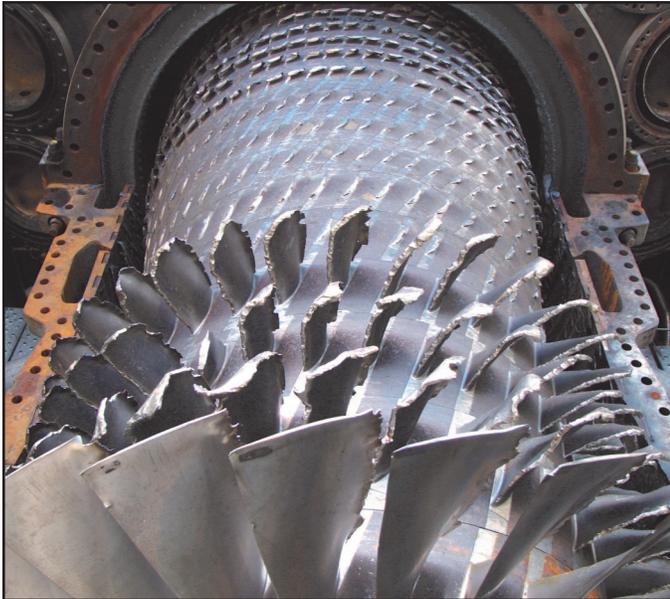


Figure 2. Elemental map showing the lack of dilution between the stellite and 316L stainless steel.

THIRD PARTY EXAMINATION



- Case Evaluation and Technical Data Review
- Test Methods Development and Planning
- Evidence Identification and Documentation
- Laboratory Testing and Documentation
- Critical Review of Test Data
- Concise, “Easy-to-Understand” Reporting
- Depositions and Technical Expert Testimony
- Secure Evidence Storage and Handling

As an independent third party laboratory, M&M Engineering has performed over 5,000 formal multi-party investigations, accident investigations, and failure analyses since 1977. We have provided litigation support to insurance and legal industries by way of documentation reviews, material evaluations, laboratory testing, technical reporting, and expert witness testimonies.

Our highly trained engineers, scientists, and laboratory technicians encompass a myriad of expertise in conducting comprehensive accident investigations and failure analyses. Most of our multidisciplinary staff of professional engineers, materials engineers, metallurgical engineers, mechanical engineers, and chemists hold advanced degrees and professional certifications. We are supplemented further by a network of professionals in chemical, environmental, and process engineering, as well as equipment design.

The diversity of our staff and our extensive technical experience enable us to establish the root cause of accidents or failures. Whether in the field or in the laboratory, we draw on our in-depth knowledge of the equipment and processes used in the utility, pulp and paper, petrochemical, manufacturing, and other industries, to provide our clients with the most reliable and concise test results, technical reporting, and expert testimony.



ON & LITIGATION SERVICES



M&M Engineering Associates' home office houses a 1900 square foot litigation support facility, consisting of a laboratory area, two meeting rooms, and a private office space.

The laboratory area covers 1390 square feet and houses a photography station, disassembly area, stereomicroscope with digital camera, and a metallurgical microscope. All cameras in the laboratory area are linked to a 55" television monitor located within the laboratory for group viewing.

Each meeting room is equipped with a 48" television monitor that also links to our stereomicroscope, and metallurgical microscope; allowing participants to witness examinations in all meeting spaces.

Typical laboratory support services include:

- Inventory and photographic documentation of parts/materials
- Documentation of serial numbers, model numbers, lot numbers, part numbers, etc.
- Low magnification examination and photographic documentation using a stereomicroscope
- Sectioning and preparation of specimens for fractographic and metallographic examination
- Metallographic examination of specimens and photographic documentation using a metallurgical microscope
- Hardness and/or microhardness testing of specimens
- Scanning electron microscopy (SEM)/ energy dispersive spectroscopy (EDS) examination
- Identification of material composition using optical emissions spectroscopy (OES)

Our litigation support facility is adjacent to M&M Engineering's metallurgical laboratory and machine shop, which can perform additional testing including non-destructive examination (NDE) such as wet and dry magnetic particle inspection and dye penetrant inspection, pressure testing, electrical testing, and functionality testing. M&M also subcontracts additional laboratory services such as DNA, ICP, and FT-IR.



the level of porosity is low because the gas evolution from the metal weld are suppressed and no bubbles are formed. At very slow cooling rates, porosity is also minimal because the bubbles have time to coalesce and escape from the weld pool. When the cooling rates of the weld are intermediate, porosity then becomes a problem since the conditions at this rate become optimum for formation and entrapment of gases.

Porosity can also be associated with a lack of workmanship. If the parts to be welded and consumables are cleaned and dried, the porosity risk decreases.

SHRINKAGE POROSITY

Shrinkage porosity occurs when sections of the overlay layer solidify faster than the material around it and do not have enough metal flow for a complete fill (Figure 3). This generally happens when the weld area is too hot relative to the surrounding area. From another perspective, when the part is not preheated enough, it is quenched too fast and may result in shrinkage porosity. Unsuitable composition and incorrect temperatures can also become factors in causing shrinkage porosity. Shrinkage porosity can also be caused by a combination of the all of the above factors.

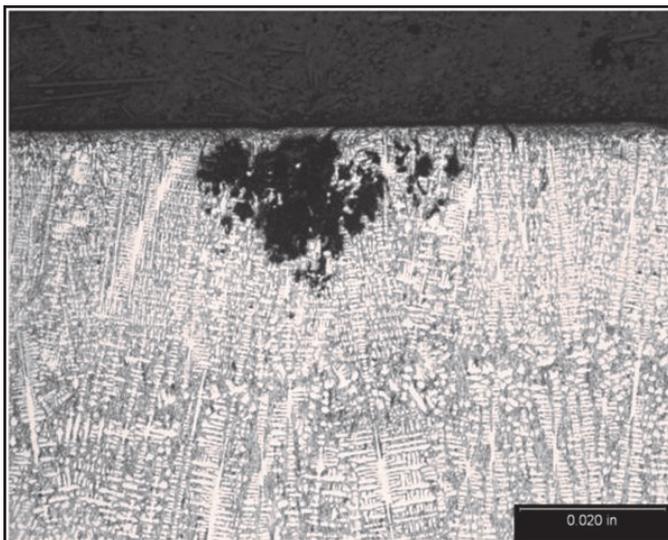


Figure 3. Shrinkage porosity at the surface of the stellite layer.

MITIGATION

Preheat

Applying heat to the base metal immediately before

welding will improve the quality of the weld/overlay.

Preheating affects these four factors:

- Slow down the cooling rate
 - A slow cooling rate helps minimize porosity since the bubbles have time to coalesce and escape from the weld pool.
- Reduce shrinkage stresses and distortion
 - When a drastic temperature change occurs, the material suffers shrinkage stresses and distortion. Shrinkage stresses and distortions will not go away but they can be minimized by preheating.
- Promotes fusion
 - Raises the material's initial temperature to ensure good weld fusion from the start.
- Removes moisture
 - Usually, it is not necessary to preheat austenitic stainless steels, unless there is condensation. If condensation is present, usually uniform heat should remove it. Preheats higher than 100°C in stainless steels can cause negative effects such as rise to carbon pickup or metallurgical instabilities. In martensitic stainless steels, a high preheat temperature is recommended and cooling must be controlled. Ferritic stainless steels are rarely preheated.

Post-Weld Heat Treatment

A post-weld heat treatment (PWHT) is typically applied to prevent brittle fracture and to reduce residual stresses from processing. PWHT also can help by reducing the hardness gradient between the base material and the weld, and enhancing the material's properties such as ductility and tensile strength. Typically, there is no need for PWHT when welding overlay on austenitic stainless steels (i.e., 316L). Having said that, a PWHT after applying an overlay will most likely enhance the mechanical properties, such as fracture toughness and ductility. By either annealing or stress relieving the component, the hardness gradient between the overlay and substrate will be reduced.

A higher hardness gradient usually causes higher stress concentrations along the weld line, which then becomes more prone to cracking.

Additionally, the weld and heat affected zone (HAZ) will be prone to Hydrogen Induced Cracking (HIC) if any hydrogen was entrapped during the original overlaying process. In order for HIC to occur, three main factors are required: a sensitive microstructure, stress, and hydrogen. The stress source is caused by the residual stresses along the weld line. Austenitic stainless steels have a sensitive microstructure. If the fusion line becomes sensitized, the fusion line loses its strength due to the hydrogen diffusing into its grain boundaries and becomes brittle (Figure 4).

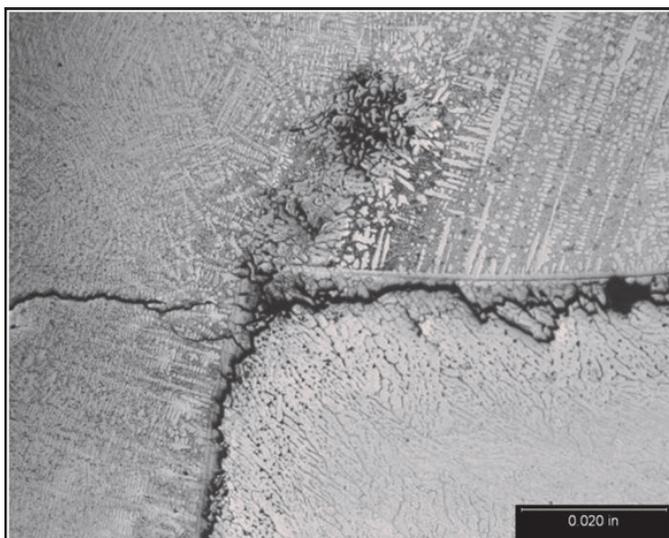
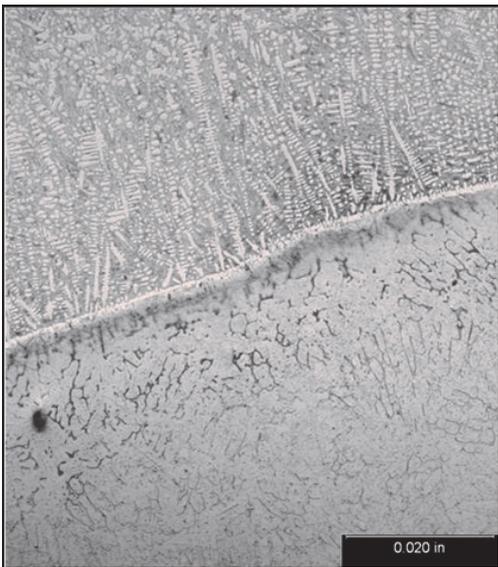


Figure 4. Porosity and cracking at the fusion line between the stellite overlay and 316L stainless steel.

The PWHT should be performed outside the ranges of 430 - 900°C (806 - 1652° F). Any PWHT performed in this temperature range will cause chromium carbides to precipitate within the grain boundaries (sensitization) and will reduce the corrosion resistance of the alloy. A PWHT, besides reducing the hardness gradient, will stress relieve the weld line and HAZ. This will also result in an increase in fracture toughness.

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Now available online!

Boiler Tube Failure Handbook

The handbook presents examples of common failure mechanisms in a variety of boilers including power boilers, recovery boilers, and Heat Recovery Steam Generators. Visual examination may help the equipment operator decide whether further metallurgical examination and root cause analysis is warranted. The only sure way to determine a failure mechanism and root cause is a full metallurgical examination.

To view the handbook, visit: <http://mmengineering.com/boiler-tube-failure-handbook/>

CORROSION 2015
Collaborate. Educate. Innovate. Mitigate.

Catherine Noble, Senior Engineer with MMEA will be attending CORROSION 2015 in Dallas, Texas on March 15-19. She is also chairing the STG 38 Symposium on Corrosion Issues in Pulp, Paper, and Biomass Conversion. The symposium takes place on Monday, March 16th with a committee meeting to follow.

Max Moskal, Principal Engineer with MMEA, will also be attending CORROSION 2015, and presenting his paper "Recovery Boiler Tube Failure by Mechanisms of Stress-Assisted Corrosion and Phosphate Hideout."

For more information about this event, visit: <http://nacecorrosion.org/>



Preventing Failures in Steam Generating Equipment

February 17-18, 2015 — Leander, Texas

M&M Engineering will host their 4th annual workshop for producers of steam, be it used in power or process applications. The two day workshop focuses on the issues most common in steam generating systems and is applicable to many industries including: pulp and paper, refining, petro-chemical, and power generation.

Seating is limited - register TODAY!



Day 1

Day 2

- | | |
|---|--|
| <ul style="list-style-type: none"> • Equipment Associated with Steam Generation – A Primer • Utility Feedwater Heaters and Damage Mechanisms • Water Touched Boiler Tube Damage Mechanisms • Steam Touched Boiler Tube Failure Mechanisms • Introduction to Nondestructive Testing & Inspection Contracting • High Energy Piping: Damage Mechanisms and Corrections | <ul style="list-style-type: none"> • Introduction to Failure Analysis • Failure Investigation Principles for Combustion Turbines • Basic Steam Turbine Failures • Condenser and Cooling Water Failures • Damage Mechanisms in Deaerators • Water and Steam Chemistry-Influenced Failures in the Steam Cycle • Discussion and Wrap Up <p><small>* (sessions are subject to change)</small></p> |
|---|--|

The registration fee for this two day event is \$750 (continental breakfast and lunch are included).

The registration deadline is February 6, 2015. Register online at:

<http://mmengineering.com/events/event/4th-annual-preventing-failures-steam-generating-equipment-workshop/>

Or contact Lalena Kelly by phone or email for further information:

(512) 407-3775 or Lalena_Kelly@mmengineering.com

Event Location: 1815 S. Highway 183, Leander, Texas 78641



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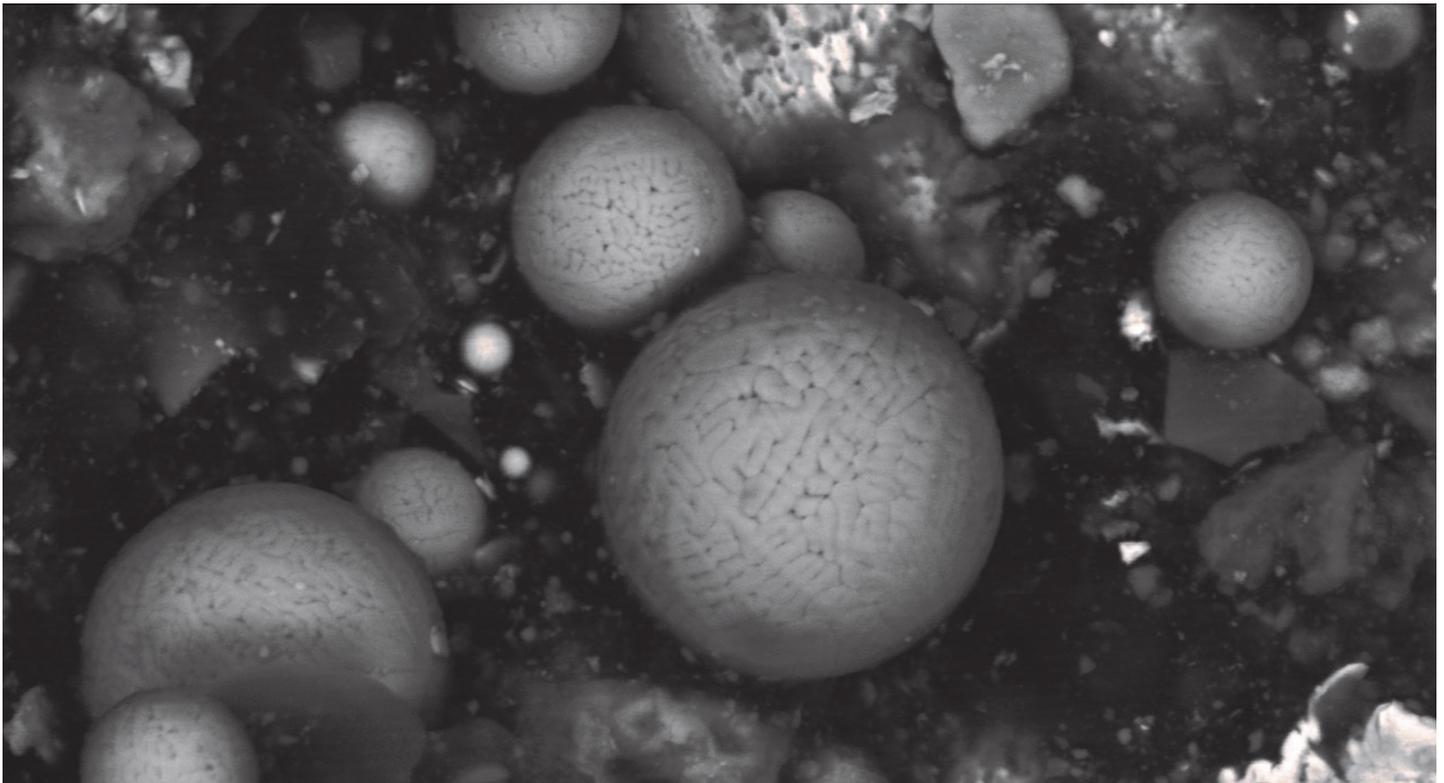
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The Metal Never Lies



Christmas Ornaments?

Happy Holidays from our family to yours!