| Subject: | Effective Date: | Initiated: |
|---|---|---|
| **Guidance for Using Stainless Steel in Low Permeability Applications** | **September 13, 2017** | Fabrication Group |
| | **Supersedes:** New | **Approved:** Engineering Department Head |

## 1. SCOPE/APPLICABILITY

This document is intended as an aid and does not in any way supersede requirements of procurement or design documents. The requirements of applicable specifications, statements of work, and drawings must be met. The following guidance can only be used if consistent with those requirements. If there is any doubt, get written clarification from PPPL or the Responsible Engineer. Following this guidance should increase the likelihood, but does not guarantee, acceptable levels of magnetic permeability.

## 2. INTRODUCTION

Magnetic permeability describes the relative ease with which a material is magnetized. Because of the strong magnetic fields in PPPL fusion devices, restrictions are placed on the magnetic permeability of materials used.

## 3. REFERENCE LIST OF CODES AND STANDARDS

PPPL Specification

C/D- ENG- SPEC-039 **Annealing 304 or 316 Stainless Steel Components**

ASM Standards

1.1 ASM Handbook Volume 4, Process and Quality Control Considerations

1.2 ASM Handbook Volume 4, Heat Treating of Stainless Steels

## 4. GUIDELINES

### 4.1. Factors Affecting Permeability

Wrought austenitic stainless steels (i.e.; plate, pipe, forgings) are typically non-magnetic ($\mu<1.02$) in the as-rolled condition. Thermal processing, welding or cutting, may result in some level of ferrite which increases the magnetic permeability of the material. Chemical composition of the stainless steel is a key predictor of its permeability. Chromium, molybdenum, silicon, and niobium promote ferrite while carbon, manganese, and nickel promote formation of austenite.

Note: Some limited ferrite is beneficial to stainless steel welds and castings as it prevents micro-fissuring and promotes enhanced resistance to stress corrosion cracking. Therefore austenitic steel welding materials are typically specified to have a composition that will yield some delta ferrite in the weld deposit. Similarly, while higher carbon content may result in lower permeability, it also has a negative effect on corrosion resistance and so very high carbon values should be avoided.

Another permeability factor is the amount of cold working. The greater the reduction from cold working, the greater the increase in magnetic permeability.

### 4.2. Considerations for Obtaining Material with Low Magnetic Permeability

Options for controlling ferrite content include material choice, for example Type 316 stainless steel composition (16Cr 10Ni 2Mo typ.) predicts that it will contain less ferrite and so have lower magnetic permeability than Type 304 (18Cr, 8Ni, typ.).

Since most PPPL work involving stainless steel specifies use of Type 304, the following approaches can be used to improve the chances of obtaining and retaining low magnetic permeability.

1) To avoid the cold-working effects, hot formed steel should be purchased. The forming method should be clearly indicated on the material certification.
2) When the chemical composition can be reviewed prior to purchase, choosing the material that is lower in Cr, Mo, Si, and Nb and higher in C, Mn, and Ni should show lower permeability. There are no "magic" numbers. However, when a choice can be made between two otherwise equivalent pieces, choosing the material with higher nickel should give you the piece with lower permeability.
3) Consider the ferrite content, expressed as the Ferrite Number (FN), when selecting weld filler materials. FN between 2 and 4.5 should produce welds with acceptable permeability and with properties that resist corrosion and cracking. When welding Type 304, a common filler material choice is ER308. If the material used has an FN in the 2-4.5 range, it should produce welds with acceptable permeability. However, since ER308 often has an FN greater than 5, it may be easier to find ER316 with ferrite content in the desired range. (As an alternative, use of high nickel alloy filler metal (0 FN) may be suitable where permitted by the engineering design and specifically authorized by the engineer.)

### 4.3. Measuring Permeability

PPPL uses a Severn[1] Permeability Indicator. This simple comparator has a magnet on a pivoting arm. A reference standard of known permeability is placed on one side of the magnet and the material under test on the other. By noting whether the magnet is more attracted to the reference standard or the test material, the relative magnetic permeability of the test material can be determined. The range of reference standards supplied with the comparator is specified by the customer at the time of purchase.

### 4.4. Reducing Permeability

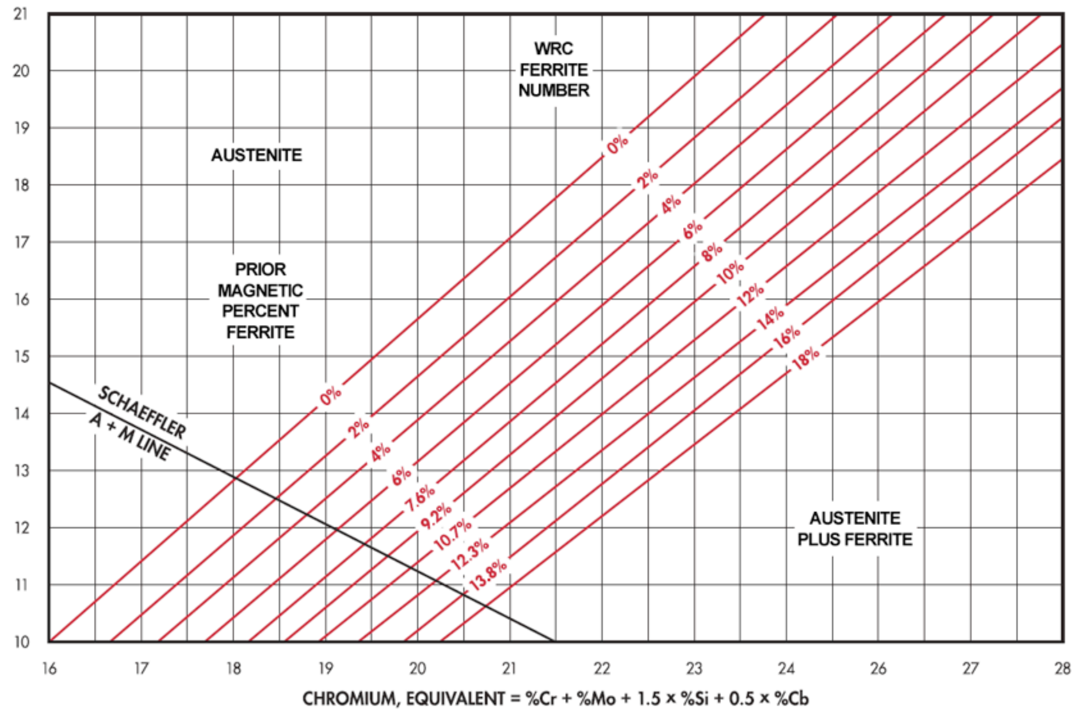
Careful annealing of stainless steel can reduce the magnetic permeability somewhat. This option should be used with great care. First, be sure that annealing will not make the item unsuitable for its application by obtaining written authorization from the cognizant PPPL engineer. Second, the annealing time, temperature and cooling rate are critical, so the applicable ASTM standard should be followed. For more information on how to anneal stainless steel refer to PPPL Specification C/D-ENG-SPEC-09.

### 4.5. Other Considerations

Bolts, nuts and washers should not be heat treated as it will reduce the ultimate strength of the fasteners. When it is necessary to use materials with relatively high magnetic permeability, such as welds, fasteners, etc.; using smaller fasteners or welds that are toroidally symmetrical (with concurrence of the Responsible Engineer) will reduce their impact on the experiment and may be allowable.

[1] Severn Engineering Company, Auburn, AL

**DeLong (FN) Diagram for Stainless Steel Weld Metal**




Calculate the nickel and chromium equivalents from the weld metal analysis. If nitrogen analysis of the weld is not available, assume 0.06% for GTA and covered electrode, or 0.08% for GMA weld metals. If the chemistry is accurate the diagram predicts the WRC Ferrite Number within plus or minus 3 in approximately 90% of the tests for 308, 309, 316 and 317 families.

| Factor | Increases Permeability | Reduces Permeability |
|---|---|---|
| **Thermal Processing** | Welding, Cutting | Heat Treatment |
| **Chemical Composition** | Chromium, Molybdenum, Silicon, niobium | Carbon, Manganese, Nickel |
| **Mechanical Processing** | Cold working (machining, bending, etc.) | Hot forming |

Factors that Affect Permeability of Austenitic SS