



Our Philosophy

New Hampshire Materials Laboratory has one goal—to help you solve your technical problems at a reasonable cost. Tests help, but are not always enough. Our team of dedicated and experienced professionals has both the skills and the backup facilities to serve in the following:

- Failure Analysis
- Material Certification & Compliance
- New Product Testing
- Mechanical Properties
- Tensile and Compression Testing
- Heat Treat problems and Verification
- Reverse Engineering
- Weld & Life Testing
- SEM & EDS

Martensite in Austenitic Stainless Steel Welds

Background

Martensite is a crystal structure that forms in steels during rapid cooling. Cooling rates are dependent on particular chemistry of the steel. Certain conditions can be met that will cause martensite formation in austenitic stainless steels.

Long, needle-like clusters of crystals in the metal characterize martensite. The martensite crystals have a highly stressed body centered tetragonal structure. In austenitic stainless steels and the austenite phase of a magnetic (austenitic/ferritic) stainless, when martensite is present in a weld, don't expect it to pass the bend test. The weld will not have the toughness and ductility that we normally expect from a stainless steel, and in some circumstances there may be unanticipated corrosion.

This issue of Nuts and Bolts describes the metallurgical tools we use to predict whether a weld is at risk for martensite.

If additional information relative to the metallurgical details is needed, please call or contact us by e-mail, Lab@NHML.com.

Fillet Composition

With only one exception, adding alloying elements to steel allows martensite to form at a slower cooling

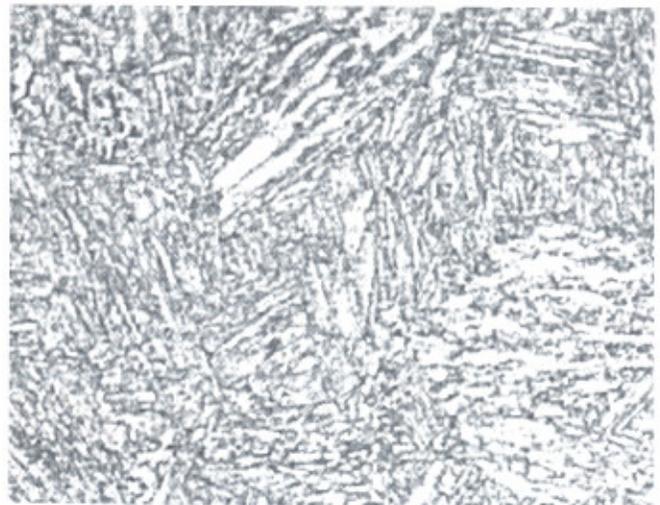


FIGURE 1:
One martensite crystal formation in 410 stainless steel

rate. That exception is cobalt, which works the other way. With cobalt, martensite will form at a faster cooling rate.

We recognize that the actual composition of the weld fillet will vary along a line running across or bisecting the weld fillet. On the centerline, we expect the fillet composition to be closer to the wire composition. Approaching each base metal, the composition shifts from the filler metal composition more towards each base metal. In welding metallurgy, we mark on the phase diagram the chemistry of one base metal and the chemistry of the filler wire. We find that the actual fillet compositions lie on the line drawn on the phase diagram. When the base metals are different,



it takes different lines on the phase diagram to represent the compositions approaching each base metal.

Predicting Martensite

The results and microstructural consequences of this sort of exercise in physical metallurgy appeared in 1949 as the "Schaeffler Diagram". Our technology did not stand still and the Diagram iterated through several updates. The 1994 Winter Addendum to the ASME Code brought us the Welding Research Council's, "WRC-1992 Diagram" which continues to be extensively used. Still, there has been a problem associated with manganese, which brought yet another modification into use, which is the topic of this Nuts and Bolts. The analysis behind the modification appears, for example, in D. J. Kotecki, "A martensite boundary on the WRC-1992 diagram", *Welding Journal*, V 78 No. 5 p180-192.

In lots of cases the 1% manganese line satisfactorily predicts martensite or no martensite. However we sometimes encounter steels having higher manganese and quite often encounter much lower. High side examples include 1.0-1.5% manganese in a 309L filler wire, 4% in a 307, and 6% in the European 18 8 Mn filler wire. On the low side if you are joining stainless to a

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modern carbon steel, the manganese can be quite low, perhaps even 0.3%.

To enter the modified Diagram, we need to calculate two numbers roughly based on chromium and nickel content. We also have to apply a lot of welding know how as to the mixing of the metals.

Calculate the

nickel equivalent:

% nickel
+ 35 x % carbon
+ 20 x % nitrogen
+ 0.25 x % copper

chromium equivalent:

% chromium
+ % molybdenum
+ 0.7 x % niobium

The Amount of Nitrogen

One of the problems we have to also confront is the amount of nitrogen. The best shielding practice with a wire electrode might introduce no nitrogen. Flux cored electrodes tend to add nitrogen. For example, the metal in a flux cored electrode might analyze to 0.05% nitrogen while it deposits as 0.075% nitrogen. Most of us deal with the nitrogen by first plotting the points with only the known nitrogen and then we plot the nearby point based on our estimate of the actual nitrogen. The compositions at risk are those on the Diagram to the left and below the indicated manganese bands. Within the bands the diagram is known to be imprecise.

In practice, you have to cope with the range of compositions between one base metal and the filler metal, and between the other base metal and the filler metal. You could put all of your predicted nickel and chromium equivalent compositions on the graph. However, examining the diagram we see that the compositions more at risk for forming martensite are those with low nickel and chromium equivalent numbers, coupled with low manganese. After a little practice with the diagram we know pretty well which compositions are likely to be at risk and we tend to plot only those numbers.

A Warning: Notice that all of the alloying elements in the calculation contribute to hardenability. Should either base metal or the filler metal contain any unlisted elements which are known to con-

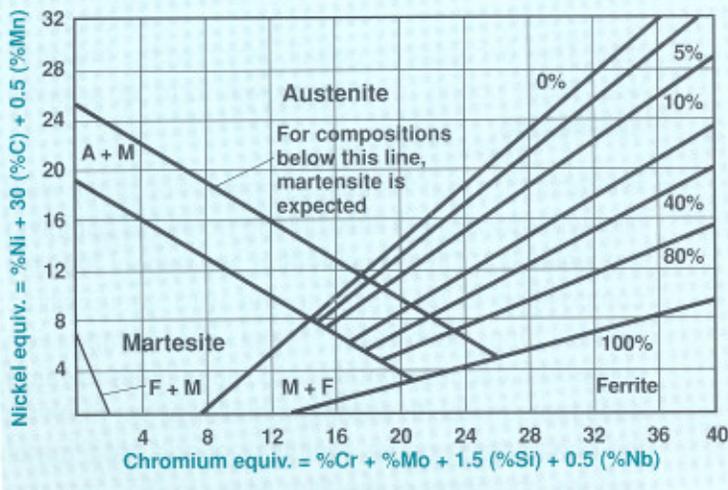


FIGURE 2: The 1949 Schaeffler diagram



tribute to hardenability then the Diagram doesn't apply! After decades of absence, tungsten is showing up mostly as a substitute for molybdenum and mostly in Russian and Chinese metals. In doing the calculation the practice is to lump the tungsten with the moly on a 1:1 basis. When forced to do it, welding metallurgists may tweak the calculations a little to reflect other unlisted elements however there isn't much of a research foundation on which to base such adjustments.

Ferrite Number

The 300 series of stainless steels is austenitic (non magnetic) while the duplex stainless steels are mixed austenite and ferrite. In the field, the amount of ferrite is measured through its magnetic response. The portable meter is calibrated for % ferrite and it is called the "ferrite number". Martensite gives a magnetic response but not as strongly as ferrite, so when it is present it contributes to the "ferrite number".

Recognize also that perfectly good austenitic stainless steel that has been heavily cold worked can become slightly magnetic and give a ferrite number even though neither ferrite nor martensite are present.

In the upper right side of the diagram there is a cluster of lines of constant ferrite number. The upper left line is 1% ferrite number which is nominally 99% austenite and 1% ferrite. The last line along the lower right side of the cluster is nominally 98% ferrite and 2% austenite.

Learning by Doing (and "cya")

Good record keeping means photocopying a bunch of diagrams and every time you confront the martensite issue you make a record of how you calculated the nickel and chromium equivalents. You plot these on the graph, draw the lines between, and estimate an adjustment for nitrogen. You note the ferrite number and whether the bend test is pass or fail.

You don't just do the exercise for samples that fail the bend test. Otherwise you won't learn the limits for welds that pass every time! If testing the weld

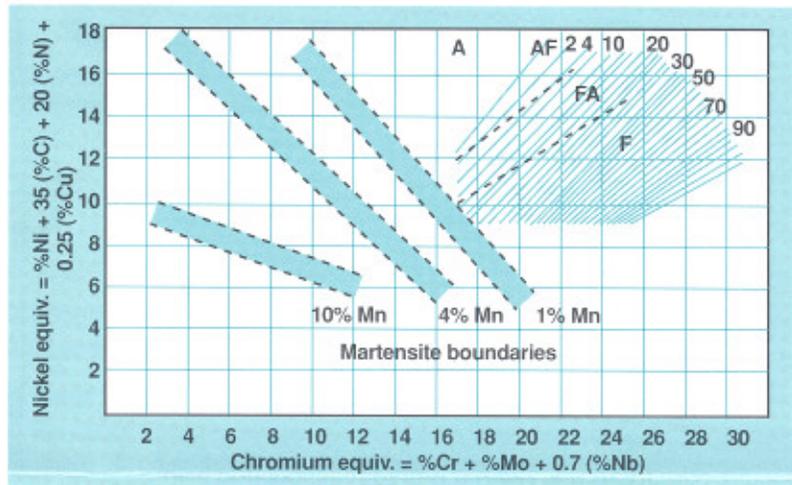


FIGURE 3: The WRC-1992 Diagram modified to reflect experience with manganese. Martensite is predicted to form with composition equivalents below and to the left of the manganese bands. Reprinted from *Advanced Materials & Process*, June 2000 p 75

for its ferrite number is worthwhile then making the record is also worthwhile. The day will come when you note the manganese is low and you make yourself into a hero when you predict the need for a little preheat.

There will be discrepancies. When it happens it most likely means that you misjudged the effect of cooling rate, or you didn't get the chemistry right, or the basic diagram is imperfect!



People at NHML...

Introducing Cullen Kulaga, Chemistry Technician

While Cullen may be the youngest person at NHML, he has the background to serve both us and our clients well. A

graduate of Maine Maritime Academy, Cullen holds a B.S. in Ocean Studies.

At NHML, Cullen operates the ICP and Leco machines in our chemistry lab. While not butting heads playing rugby football for the Seacoast Rugby Club, Cullen relaxes by working with his computer and reading.

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