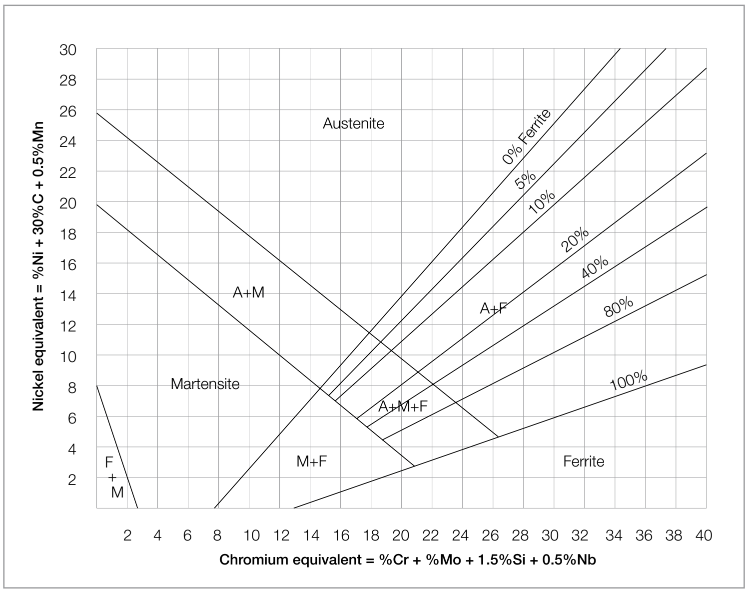
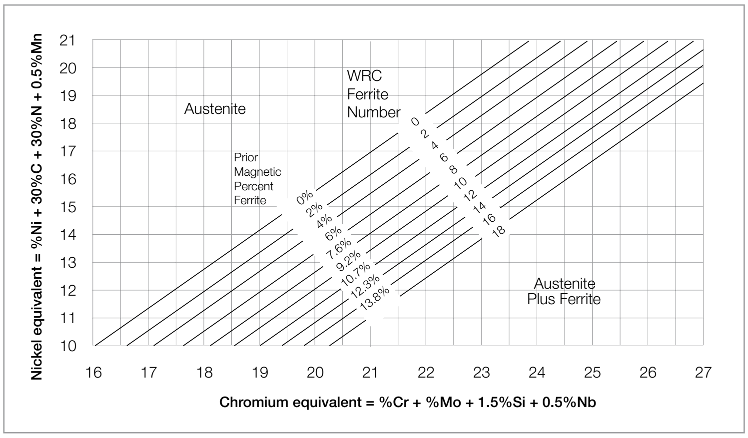
Ferrite in weld metals

Ferrite is obviously a major constituent in ferritic and duplex weld metals. Some ferrite can often also be found in martensitic and in particular in a majority of austenitic weld metals.

The weld metal ferrite content can influence a wide range of properties, including corrosion resistance, toughness, long term high temperature stability, resistance to hot cracking etc. Austenite is tougher and more ductile than ferrite, especially at low temperatures, it is not ferromagnetic and less likely to form brittle phases at elevated temperatures. On the other hand, ferrite is highly resistant to stress corrosion cracking, it is ferromagnetic and usually has a higher yield strength than austenite.



The Schaeffler Diagram



The DeLong Diagram

An important aspect of ferrite in weld metals is related to the solidification behaviour. It is widely accepted that welds which initially solidify as austenite are more susceptible to hot cracking than those that initially solidify as ferrite. This is largely due to the greater solubility of ferrite for alloying and impurity elements that promote hot cracking.

Most welds, including standard austenitic types such as 308 and 316, are therefore designed to solidify primarily as ferrite to improve hot cracking resistance. This means that the austenite is mainly formed when the initial ferrite is transformed during cooling. Consequently, the ferrite content at room temperature is not the same as during solidification and will depend on cooling rate.

Measurement and prediction of ferrite content

Ferrite determination is frequently required for weld procedure qualification and also commonly specified for filler metals. The ferrite content can either be measured by point counting techniques, magnetic methods or it can be predicted based on the chemical composition of the weld metal.

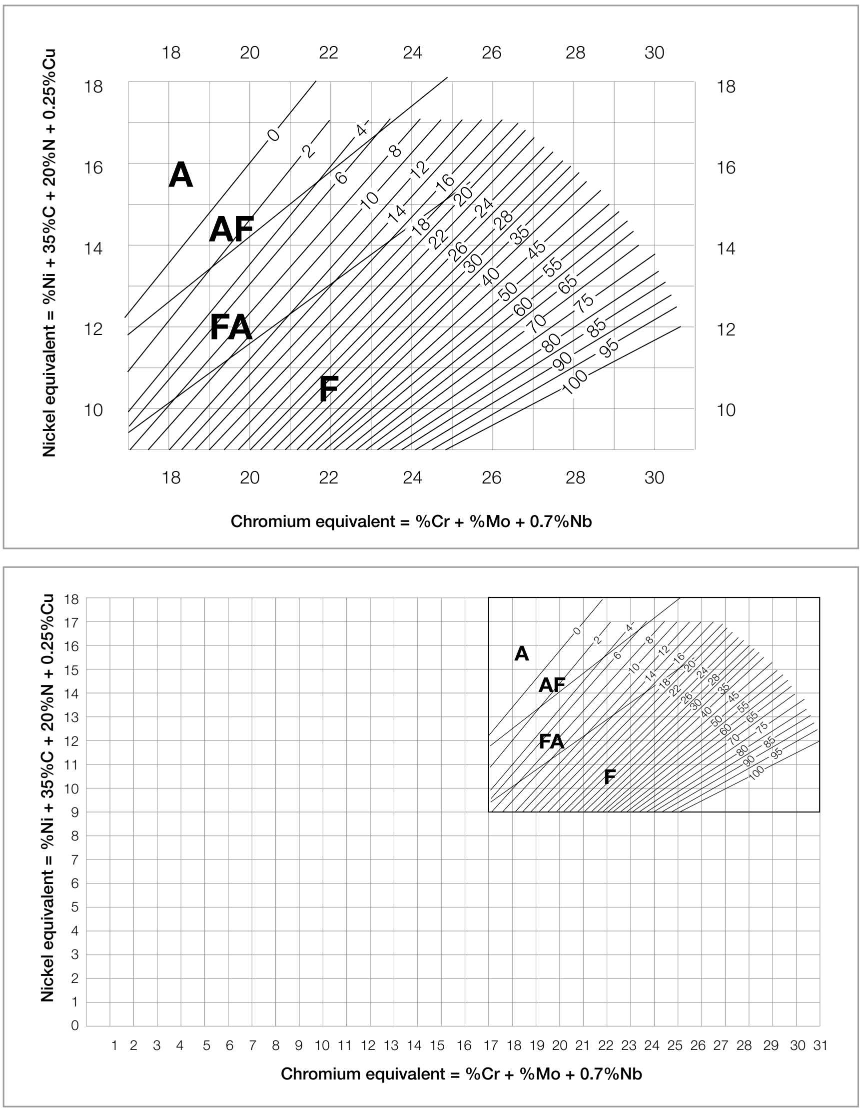
Measuring the ferrite content

There are two types of methods for measuring the ferrite content of weld metals and parent materials: (a) point counting techniques and (b) magnetic methods.

Point counting gives a ferrite content in ferrite percentage (sometimes denominated FP). Magnetic methods takes advantage of the different magnetic properties of ferrite and austenite with ferrite being ferro-magnetic, whilst austenite is not. A Ferrite Number (FN) is assigned to a given level of magnetic attraction, defined from primary standards using a magnetic beam balance known commercially as a MagneGage instrument. It is important to realise that there is no unique correlation of Ferrite Number with ferrite percentage since the FN depends not only on the ferrite percentage but also on composition. The Ferrite Number is approximately equivalent to the percentage ferrite at low values but will be larger than the percentage ferrite at higher values.

a) Point counting involves direct microscopic measurement on suitably prepared specimens and gives the ferrite content in ferrite percentage. This is a destructive method since a polished and etched metallographic section is required. It cannot therefore readily be used on completed welded fabrications, but can be used on representative welding procedure samples. The main advantage of the point counting technique is that it can be applied to all microstructures, including the narrow HAZ. Point counting is, however, relatively slow and labour intensive. Comparative studies have also shown a great deal of scatter between different laboratories and different operators.

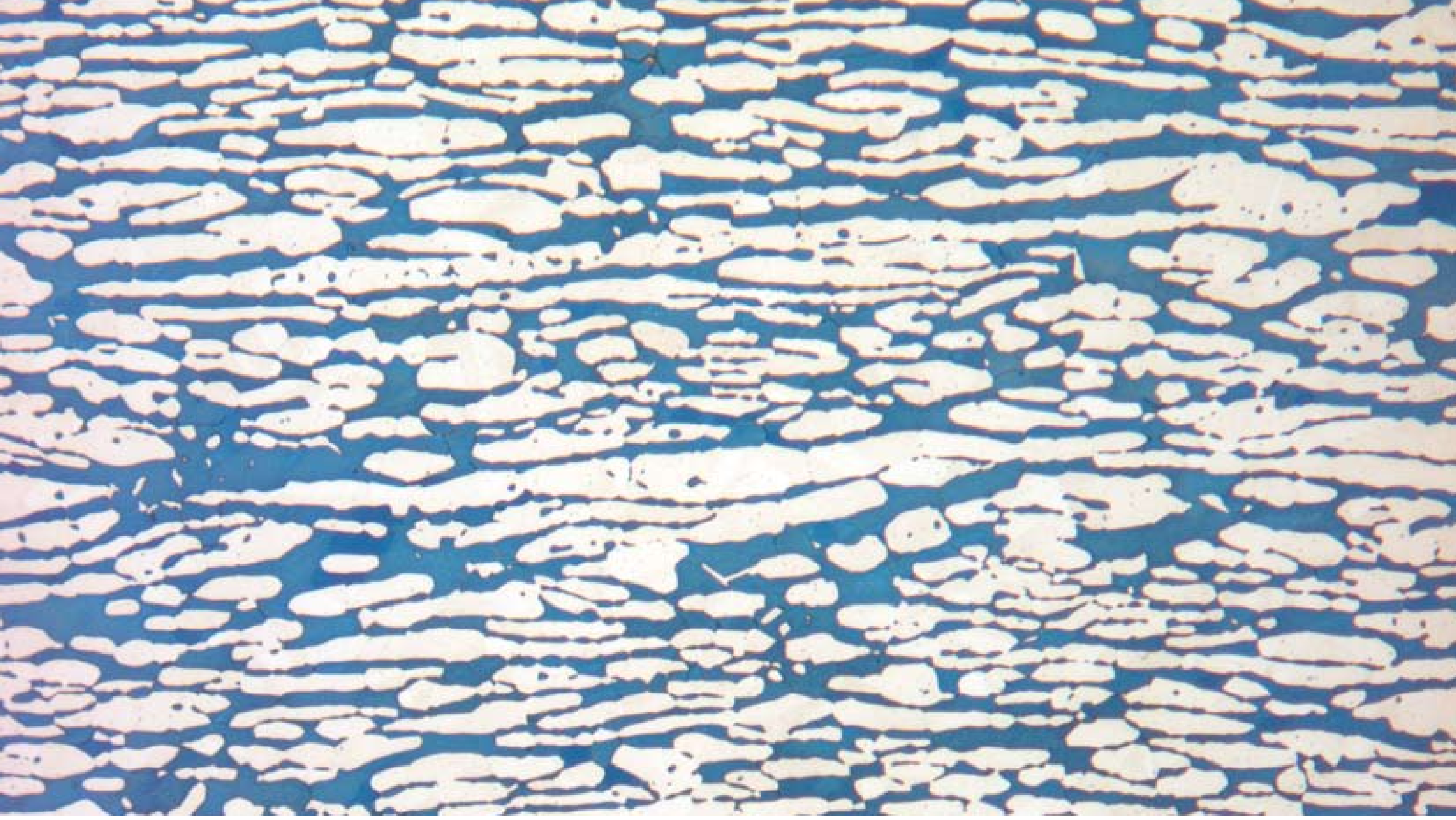
b) Instruments for magnetic measurements of ferrite content in Ferrite Number (FN) are based on one of two principles. They make either use of a permanent magnet and measure tearing-off force (e.g., a MagneGage) or utilise eddy current to measure magnetic properties (e.g., Fisher Feritscope). Both methods are in principle non-destructive although use of the MagneGage requires a flat polished specimen and is less suitable for field application. However, hand held equipment based on eddy current techniques is available and can be used on welds with a minimum of surface preparation. All magnetic methods require the use of appropriate primary standards (permanent magnet principle) or secondary standards (eddy current techniques) in order to calibrate the equipment and enable accurate measurements of FN to be made.



the WRC-1992 diagram (see Figures Z and W

Predicting ferrite content

Prediction of weld metal ferrite content can be carried out based on the chemical composition of the weld metal. A number of predictive diagrams are available with the newer diagrams making predictions



in terms of Ferrite Number (FN) instead of ferrite percentage. *The Schaeffler Diagram (see Figure X op p64)*, now more than fifty years old, is well out-dated for ferrite prediction in stainless steel welds and was followed by the DeLong Diagram (see Figure Y op p64) recognising the importance of nitrogen content. The today most widely used predictive diagram, and the one recognised by the ASME code since 1995 is the WRC-1992 diagram (see Figures Z and W op p65). Other systems, including some based on Neural Networks are also available. All these methods depend on an accurate chemical analysis of the actual weld deposit. When certified compositions of the welding consumable are used, it must also be recognised that these will not necessarily be the same as the deposit composition, depending on dilution by parent materials and welding parameters.

Comments

When specifying, measuring or predicting ferrite contents one should be aware of some basic facts:

- The ferrite content of real weldments is affected by a number of factors the most important typically being filler composition, dilution with parent material, nitrogen pickup and cooling rate.
- Ferrite is not homogeneously distributed within a weld. For example, the ferrite content is generally lower at the interface between two weld passes since heating by deposition of the subsequent adjacent pass causes some ferrite to transform to austenite.
- To require a ferrite range after post-weld heat treatment is in general irrelevant as ferrite transforms to other phases during PWHT.
- Measuring and predicting ferrite content is not an exact science:
  - It is unrealistic to require both a measured and a calculated FN for a given weld metal to be within a narrow range.
  - Chemical analysis includes variability and even the WRC-92 Diagram has a possibility of error on the order of ± 4 FN in the 0-18 FN range.
  - A study involving 17 laboratories in 8 countries organised within the International Institute of Welding indicated that scatter of about ± 20 % of the measured value should be expected between different laboratories when testing real welds.

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- *ASTM E562-02. Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count.*
- *ISO 9042: 2002. Steels – Manual point counting method for statistically estimating the volume fraction of a constituent with a point grid.*
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Joining of Dissimilar Steels

Different types of stainless steels can normally be welded to one another without difficulty. It is, however, essential that a consumable with at least the same mechanical strength and corrosion resistance as the poorest of the base materials is used and that the recommendations for welding these are followed.

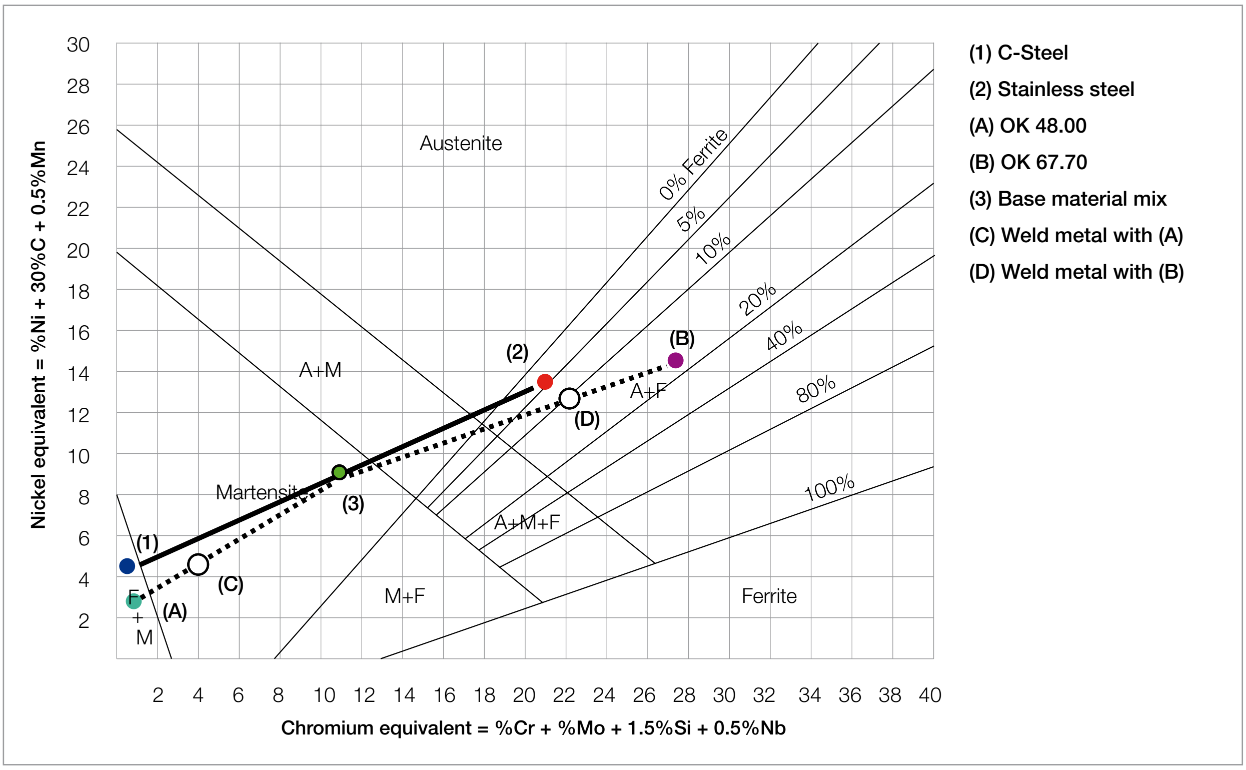
Stainless steels can also be welded to mild or low-alloy steels with excellent results if the steel has a reasonable weldability and if certain straightforward guidelines for the avoidance of cracking are followed. The same basic metallurgical considerations apply also to cladding of mild or low-alloy steels with a stainless layer as well as welding of stainless steel/ mild or low-alloy steel compound material.

The main concern during welding is to avoid cracking in the weld metal and in the base material heat affected zone (HAZ). Cracking can be either hydrogen assisted cracking or hot cracking depending on base and filler metal and on the welding procedure.

Weld metal considerations

The dilution of the filler metal by the base material must be taken into account to avoid the formation of hard and brittle or hot cracking susceptible structures. A mild steel filler metal will result in a highly alloyed brittle martensitic microstructure when deposited on a stainless steel. Using a standard stainless filler metal will usually result in the same unfavourable microstructure when welding on a mild steel. In both cases the hard and brittle regions of the welds are very likely to show extensive cracking.

There are three main approaches to produce sound crack resistant dissimilar welds between stainless and mild or low-alloy steels. Typically the first approach is preferred. The most common approach is to aim for a weld metal composition giving an austenitic



structure with some ferrite. As discussed in the " Ferrite in weld metals" section this will produce a very crack resistant and ductile weld. Typically overalloyed consumables of the (in wt.%) 23Cr 12Ni (with or without Mo) and 29Cr 9Ni types are used. A duplex filler can in most cases also be used with good result.
A similar but somewhat different approach is to use fillers depositing a more or less fully austenitic weld metal. In this case alloying with relatively high levels of Mn is needed to ensure crack resistance. A common type of filler is 18Cr 8Ni 6Mn.
Ni-base fillers should be used for service temperatures above approximately 350-400ºC to minimise carbon migration into the weld.

A diagramme such as the Schaeffler Diagram or the more recent WRC-1992 Diagram can be used to predict the microstructure of the weld metal. The WRC-1992 Diagram is likely to give a more precise prediction of weld metal ferrite content but the Schaeffler Diagram has the advantage of showing the structure for any steel weld metal composition. An example is presented in the figure on page 86 illustrating the joining of mild steel and 18Cr 12Ni 3Mo type stainless steel.

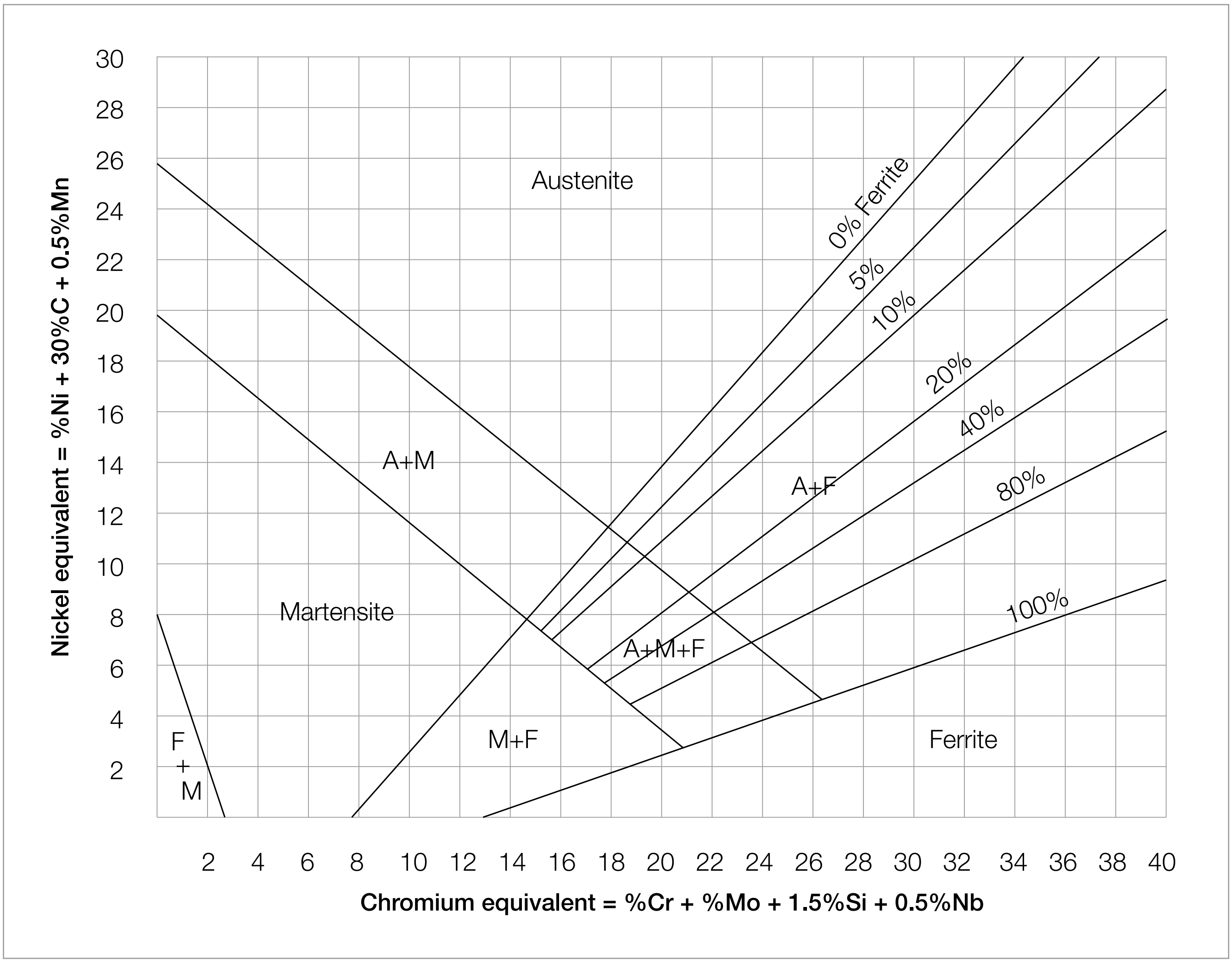
Example
Prediction of weld metal microstructure of a dissimilar joint between a stainless steel (1: 18Cr 12 3Mo) and a mild steel (2) welded with either an unalloyed consumable (A: OK 48.00) or an overalloyed stainless electrode (B: OK 67.70).

Step1: Calculate Nickel- and Chromium-equivalents from steel and consumable compositions and plot these in the diagram.
Step 2: Connect the two steel compositions with a line.
Step 3: Assume that equal amounts of the base materials will be fused. Mark the position on the line halfway between the two steel compositions (3).
Step 4: Connect the halfway point and the position of the consumable compositions of interest with lines.
Step 5: The weld metal composition is given by a point located X% of the distance between the halfway point (see step 3) and the consumable composition point. X is the assumed dilution which is typically 25-40 % for MMA, 15-40% for MIG /MAG, 25-100% for TIG and 20-50% for SAW. In this example the dilution level is assumed to be 30%.

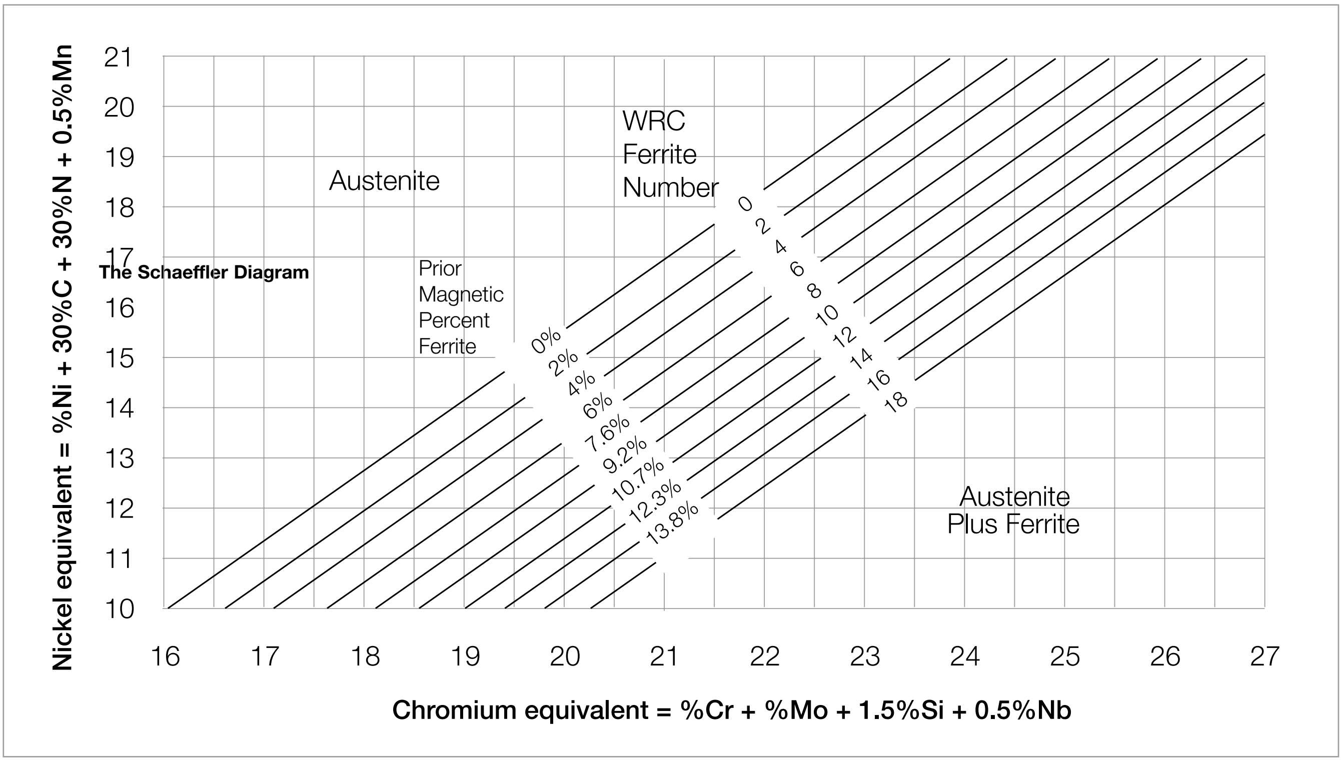
The overalloyed stainless consumable will, as shown by the example, give a desired ductile and crack resistant austenitic weld metal with some ferrite (point D). Using an unalloyed consumable will however produce a martensitic weld metal (point C) which is harder, brittle and likely to crack.

Parent metal HAZ considerations
When joining dissimilar steels it is important not only to select a consumable giving the desired weld metal structure when diluted by parent materials. The weldability of the steels must also be considered. A simple, although often overly conservative, guide is to use the same preheat, interpass temperature, post-weld heat treatment (PWHT) etc that would be used when welding the steels to themselves. However, a lower preheat can often be tolerated when an austenitic stainless or Ni-base filler is used.

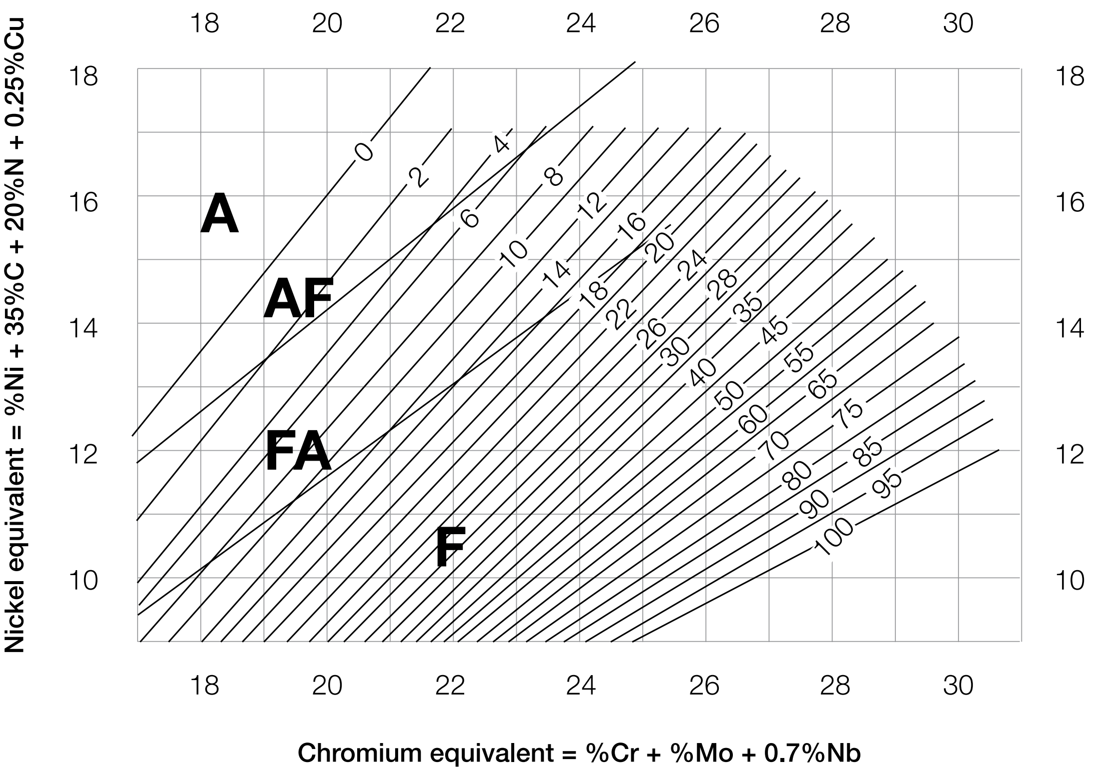
A PWHT in the range 500-700ºC, that is commonly used for mild or low-alloy steels, can cause sensitisation (see Corrosion Types) of a stainless steel or weld metal, in particular for unstabilised grades with a high carbon content. PWHT might also cause embrittlement due to precipitation of intermetallic phases. The effect is more pronounced for weld metals with higher ferrite contents. A restriction to maximum 8-10 FN is therefore common, for example in cladding of low-alloy steels, when a PWHT is required.

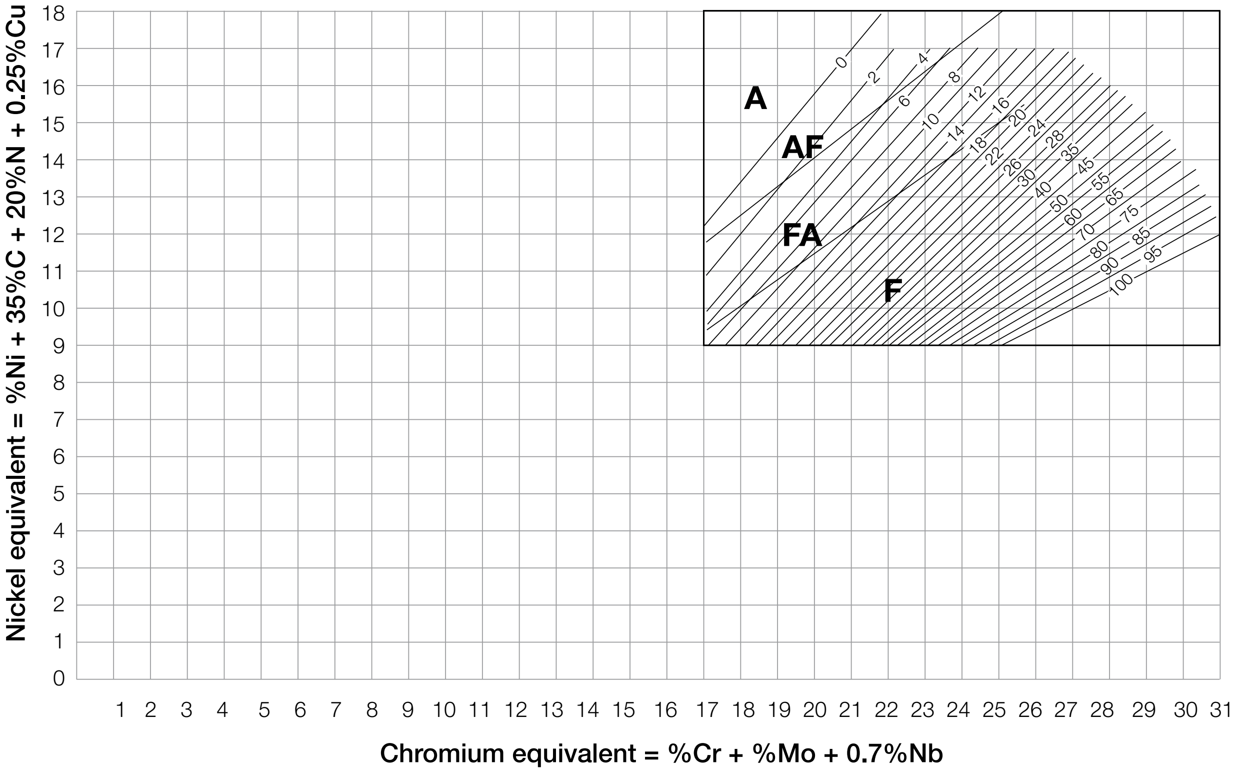


The Schaeffler Diagram



The DeLong Diagram





the WRC-1992 diagram (see Figures Z and W