



SCHAEFFLER DIAGRAM

CALCULATION OF STRUCTURE FOR STAINLESS STEELS

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1. CONDITIONS

The Schaeffler diagram does evaluate the presence of austenite, ferrite, bainite and martensite depending on the chemical composition and the proper cooling+(or heat treatment) after pouring.

The reality will always be somewhat less (austenite, martensite) because, in the case of austenitic stainless steel the cooling will be slower than required.

The limits, for the chemical composition are:

C	< 0,2 %	N =	0,05 % for % Cr	0 - 18 %
S	< 1 %		0,07	18 - 25 %
Mn	< 4 %		0,10	> 25 %
Mo	< 3 %			
Nb	< 1,5 %			

These percentages are those of the element as present in the matrix, not in carbides or any other component as nitrides

This diagram is interesting because, by quantifying the amount of types of structures (ferrite, martensite, austenite), it does give an indication that the material will comply with the standard. This is possible at a time that the metal is still in the melting furnace because it does use the chemical composition that is taken before pouring. In this way corrections of the chemical composition are still possible.

It is very useful for austenitic stainless steels because the amount of ferrite must be restricted (material becomes magnetic) and for martensitic stainless steels because the amount of delta-ferrite must be controlled.



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Another factor, which must be avoided, is the presence of carbides. The carbides do decrease the ductility but also the corrosion resistance (carbides remove chromium from the matrix). The carbides also lead to some magnetic behaviour of austenitic stainless steels. It mostly concerns and the chemical composition and the cooling after pouring and if applicable, heat treatment.

Where are which structures?

Limited by the coordinates (Creq-Nieq):

- Austenite : above the lines (0-25) till (16-12) till (36-36)
- Ferrite : under the line (11-0) till (36-9)
- Duplex : within the lines (36-36) till (16-12) till (22-4) till (36-9)
- Martensite : within the lines (0-7) till (3-0) till (7-0) till (12-8) till (0-19)

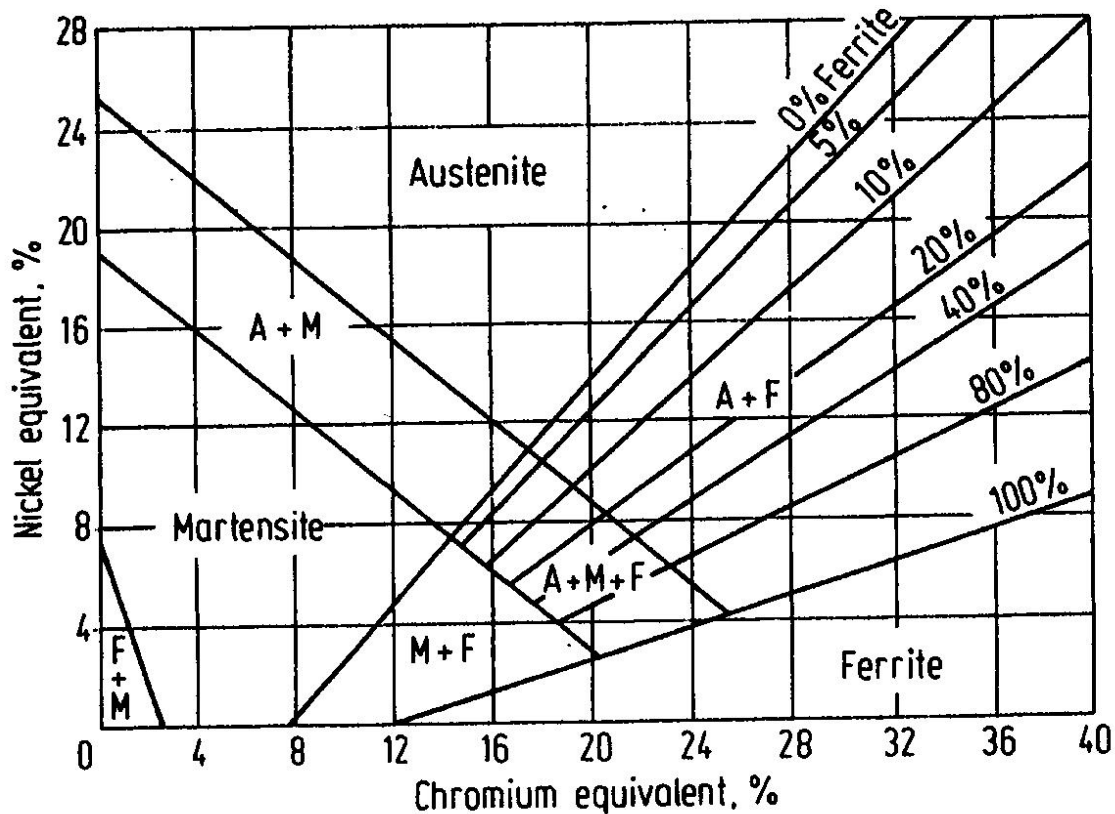
“Precipitation hardening” types are mostly located in the zone with the presence of “austenite + martensite” or “austenite + martensite + ferrite”.

Which are the structures for the commercially available stainless steels?

- Austenite : austenite + 0 - 5 - 10 % ferrite
- Ferrite : ferrite + carbides (chromium-carbides, TiC, NbC...)
- Duplex : 40 - 60 % austenite, 60 - 40 % ferrite
- Martensite : martensite + (0 - 5 %) carbides + (0 - 15 %) delta-ferrite
- Precipitation-hardened :
martensite + austenite + (ferrite) + intermetallic components

A stainless steel needs a minimum of 12 % of chromium in the matrix. Due to this condition, the part of the graph below a chromium-equivalent of 12 % is not applicable.

2. SCHAEFFLER DIAGRAM



Schaeffler É de Long diagram

$$\text{Creq} = \% \text{ Cr} + 1,4 (\% \text{ Mo}) + 0,5 (\% \text{ Nb}) + 1,5 (\% \text{ Si}) + 2 (\% \text{ Ti})$$

$$\text{Nieq} = \% \text{ Ni} + 30 (\% \text{ C}) + 0,5 (\% \text{ Mn}) + 30 (\% \text{ N})$$

There are several formulae for the nickel- and chromium-equivalent, each of them giving a somewhat better result for a particular type of stainless steel. In this case we use the formula as indicated here.

The most important is that a foundry does use one formula and check the structure. By doing this they can always evaluate the influence of a fluctuating chemical composition.

The latest version of Creq and Nieq are:

$$\text{Creq} = \% \text{ Cr} + 1,0 (\% \text{ Mo}) + 0,5 (\% \text{ Nb} + \% \text{ Ta}) + 1,5 (\% \text{ Si}) + 2 (\% \text{ Ti}) + (\% \text{ W} + \% \text{ V} + \% \text{ Al})$$

$$\text{Nieq} = \% \text{ Ni} + 30 (\% \text{ C}) + 0,5 (\% \text{ Mn}) + 30 (\% \text{ N}) + 0,5 (\% \text{ Co})$$



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3. CARBIDES

The carbides formed at high temperatures (500 to 850 °C) will be of the type $M_{23}C_6$. Those formed at lower temperatures, during tempering or stress relieving, will be of the types M_3C , M_7C_3 and $M_{23}C$.

More alloying elements will initiate complex carbides:

Tungsten	W	M_2X	X is alloying element
Molybdenum	Mo	M_2X and $M_{23}C$	M is (Fe, C, X)-combination
Vanadium	V	MX and $M_{23}C$	
Niobium	Nb	MX	
Titanium	Ti	MX	
Chromium	Cr	$M_{23}C_6$, M_7C_3 and in a lesser degree M_3C, and $M_{23}C$	

The carbides take carbon and chromium out of the matrix. The first two types ($M_{23}C_6$ en M_7C_3) do contain about 40 to 60 % of chromium. The amount of chromium compared to the amount of carbon, taken out the matrix by the $M_{23}C_6$ carbides, can be estimated (not correct value) as:

$$\% Cr_{\text{carbides}} = 14,54 * (\% C).$$

But not all the carbon will combine with chromium to form carbides, even with a very slow (but realistic) cooling. In the special types of austenitic stainless steel, the carbon is equal or lower than 0,03 % and for these types nearly never carbides are formed. So we can estimate that this amount of carbon, at least, remains in the matrix.

So the minimum+amount of chromium, still in the matrix (for the maximum amount of carbides) is:

$$\% Cr_{\text{matrix}} = \% Cr_{\text{chemical composition}} - 14,54 * (\% C \dot{=} 0,03).$$

So, the higher the carbon, the more carbides can be formed and the faster the cooling must be to avoid their formation. See figure:

How to overcome these problems?

1. Heat treatment

Pay attention that during the heat treatment:

1. carbon dissolves very quickly in the matrix
2. chromium does not solve easily (relative large atom) and the stay at high temperature must be sufficiently long
3. too long stay on high temperature does increase the grain size of the matrix, which leads to a somewhat lower ductility.

2. An increasing amount of carbon will tend to form more austenite (present times 30 in the nickel-equivalent) but the tendency to form carbides will also increase.



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For a carbon percentage $> 0,10\%$, even with the fastest cooling, they cannot be avoided.

To avoid the formation of carbides, a special type of stainless steel is produced, having $C \leq 0,03\%$.

The austenitic types with this low carbon are designated with the letter **%L** in the (American) ASTM standards. The production of them is very difficult and an extra metallurgical treatment (vacuum, argon flushing) will be necessary, which increase the cost.

2. Another solution, except low carbon, it to stabilise the stainless steel with titanium (Ti) and or niobium (Nb). These elements have a strong tendency to form carbides, which will be formed at high temperatures (normal cooling around 1000 to $1100\text{ }^{\circ}\text{C}$). The chromium carbides, depending on the cooling rate do form in the temperature range of 650 - $900\text{ }^{\circ}\text{C}$.
If the titanium or niobium content is sufficient to combine all available carbon (perhaps except $0,03\%$), than no carbon is anymore available for the chromium.

The following ratios do comply with these conditions:

Theoretically : $\%Ti / \%C = 4$ and $\%Nb / \%C = 8$

EN-standard : $\%Ti / \%C = 5$ and $\%Nb / \%C = 10$

ASTM-standard : $0,20\% + 4(\%C + \%N) < (\%Ti + \%Nb) < 0,80\%$



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4. EXAMPLES

During the calculation, the following rules will be applied:

1. if the **real chemical composition is not known**, two calculations will be made: one with the minimum and one with the maximum values. Doing this, we obtain an area (zone), in which the real composition will be present.
2. **silicon**: mostly the maximum is given. We will calculate with:
minimum 0,3 % if the maximum is 1,0 % and
minimum 0,6 % if the maximum is 1,5 or 2,0 %.
3. **manganese**: we take a minimum of 0,6 % if only a maximum value is given.
4. **nickel and molybdenum**: the minimum is 0 % if only a maximum is given.
5. **carbon**: if only a maximum is given:
minimum 0,01 % if the maximum is 0,04 % or lower and
minimum 0,04 % if the maximum is higher as 0,04 %.

Calculations

1. GX 20 Cr 14

C	Si	Mn	Cr	Ni
0,16-0,23	1,0 max	1,0 max	12,5-14,5	1,0 max
$Cr_{eq} \text{ min}$	$= 12,5 + 0,3 \times 1,5$			$= 12,95$
$Cr_{eq} \text{ max}$	$= 14,5 + 1,0 \times 1,5$			$= 16,00$
$Ni_{eq} \text{ min}$	$= 0,0 + 0,16 \times 30 + 0,6 \times 0,5$			$= 5,10$
$Ni_{eq} \text{ max}$	$= 1,0 + 0,23 \times 30 + 1,0 \times 0,5$			$= 8,40$

This steel can be located in three area:
martensite,
ferrite + martensite and
ferrite + martensite + austenite.

Due to the presence of mostly 5 to 15 % of chromium-carbides (carbides remove and chromium and carbon from the matrix), the commercially delivered steels will be located in the "ferrite + martensiet" zone.



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2. GX 6 CrNiMo 18 10

C	Si	Mn	Cr	Ni	Mo
0,07 max	1,5 max	1,5 max	18,0-20,0	10,0-12,0	2,0-3,0

$$Cr_{eq} \text{ min} = 18,0 + 2,0 \times 1 + 0,6 \times 1,5 = 20,90$$

$$Cr_{eq} \text{ max} = 20,0 + 3,0 \times 1 + 1,5 \times 1,5 = 25,25$$

$$Ni_{eq} \text{ min} = 10,0 + 0,04 \times 30 + 0,6 \times 0,5 = 11,50$$

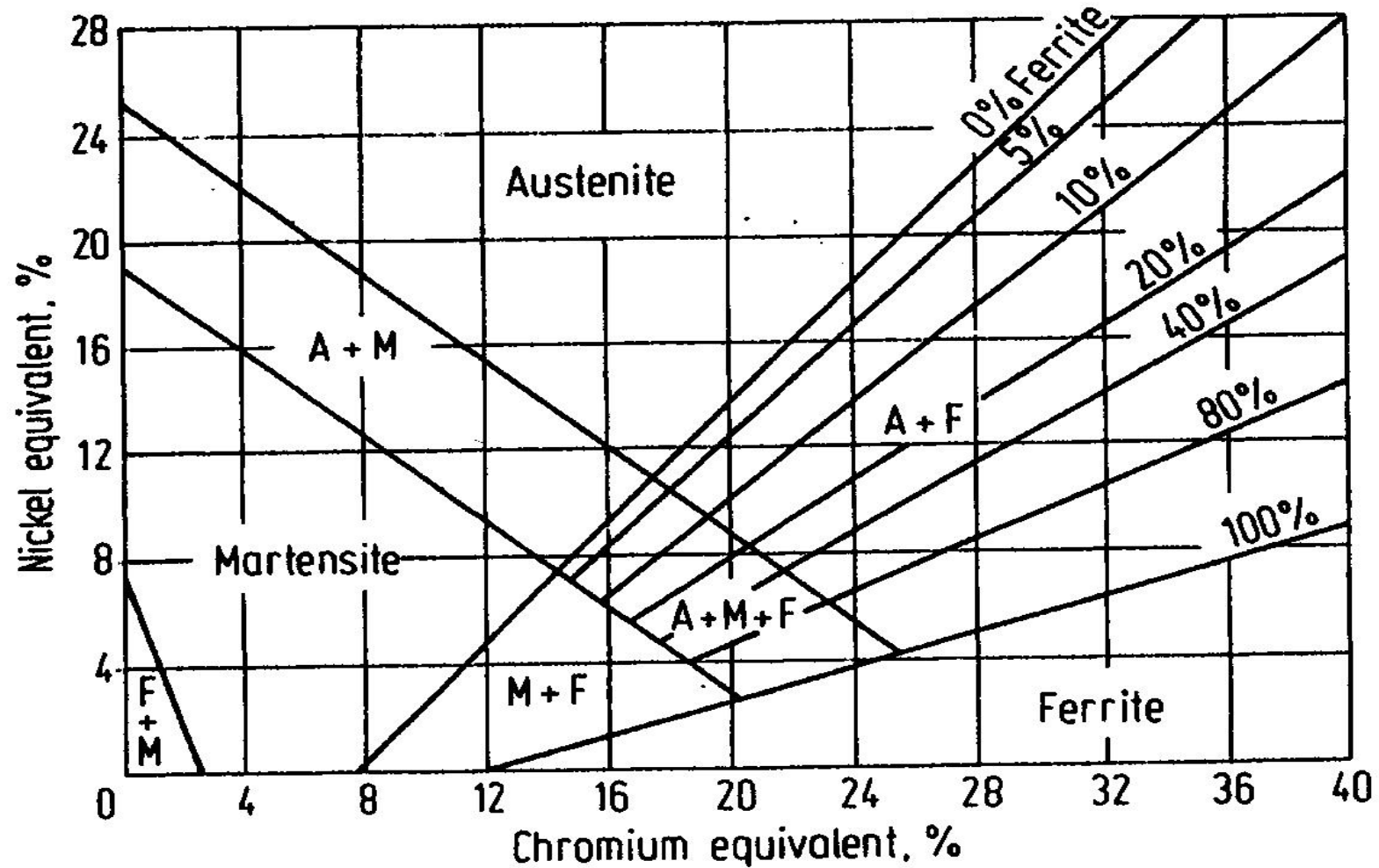
$$Ni_{eq} \text{ max} = 12,0 + 0,07 \times 30 + 1,5 \times 0,5 = 14,85$$

Dit materiaal kan mogelijk in twee gebieden liggen:
austeniet en
austeniet + ferriet.

Inderdaad er kan tot circa 10 % ferriet aanwezig zijn, ondanks dat dit staal als austenietisch bekend staat.



5. DIAGRAM (to print)





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