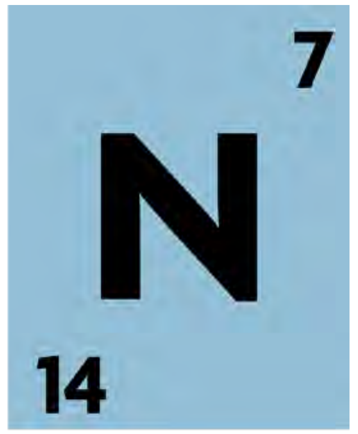
How much Niobium Can I use?

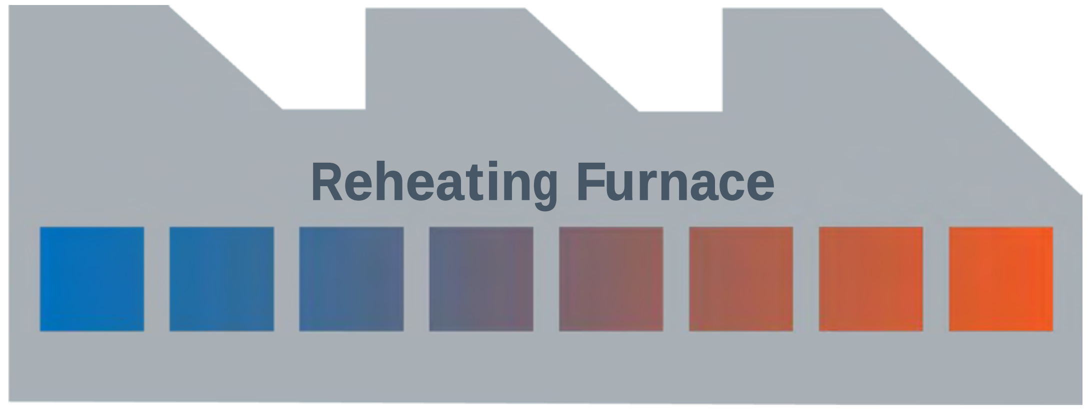
Niobium Solubility (Dissolution)

How much Niobium can I use?

A question often asked is: "How much Niobium can I use"?

- The amount of Niobium we can **practically use** during the hot rolling of steel products (*e.g. plates, strip, sections, rebar, rod etc.*) is mainly dependent on the following:



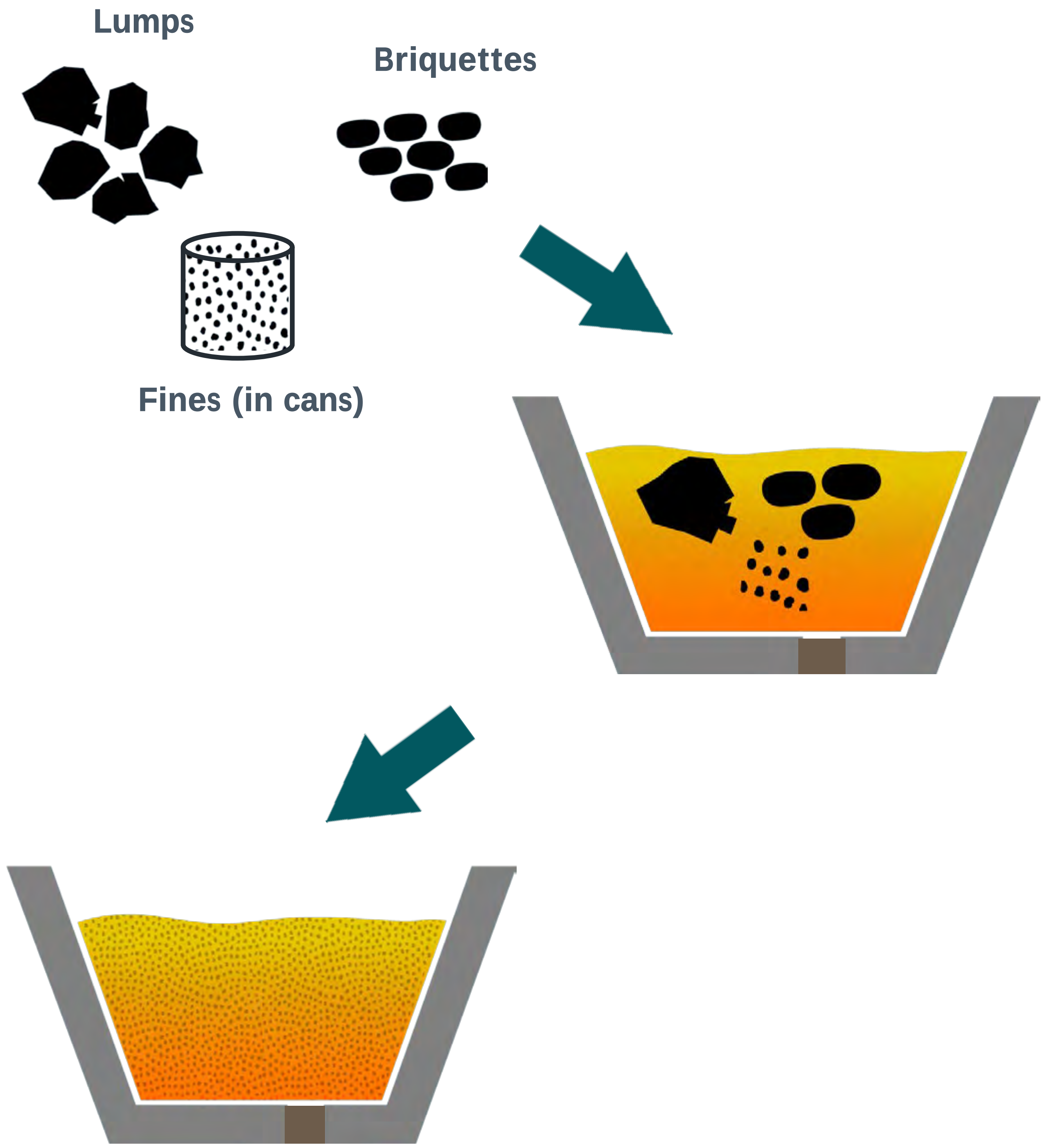


1) The Carbon content of the steel
2) The Nitrogen content of the steel
3) The furnace reheating and drop-out temperature of the cast product prior to rolling

- **The following slides will explain in simple terms why these factors are important in deciding how much Niobium we really can use in industrial practice**

How much Niobium can I use?

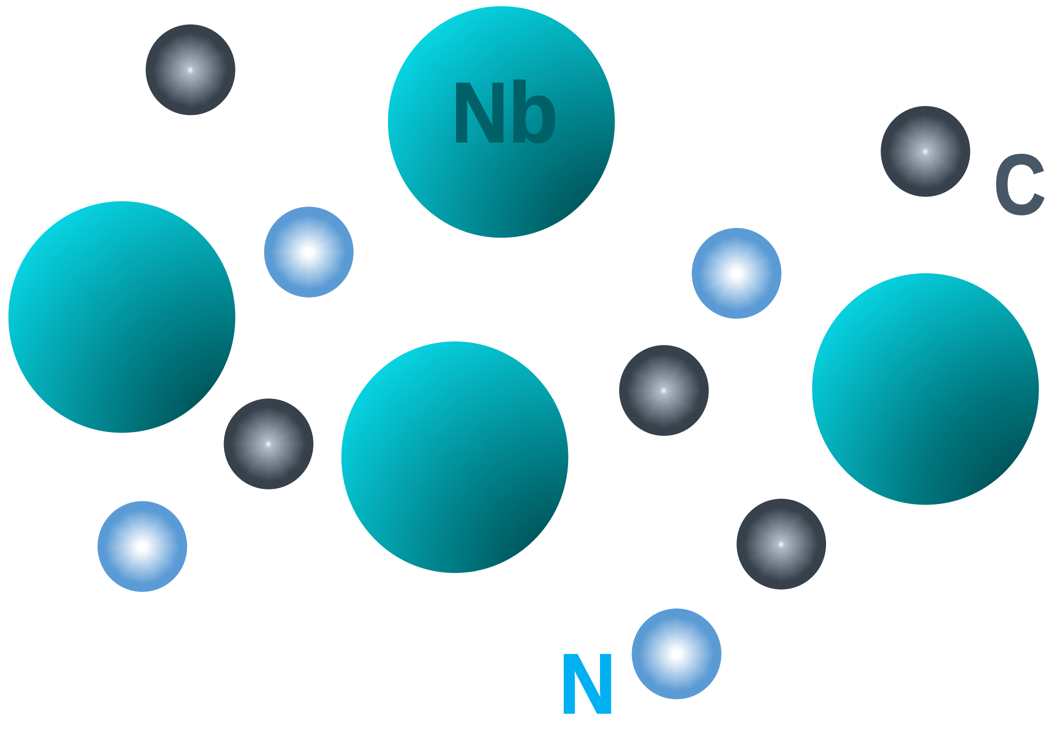
- During steelmaking Niobium (Nb) is added to liquid steel in the form of Ferro-Niobium (FeNb) lumps, briquettes or fines
- This FeNb effectively “melts” into the liquid steel (typically at >1,510ºC) and thus releases Niobium into the liquid melt
- The more FeNb we add at this stage, the more Niobium is introduced

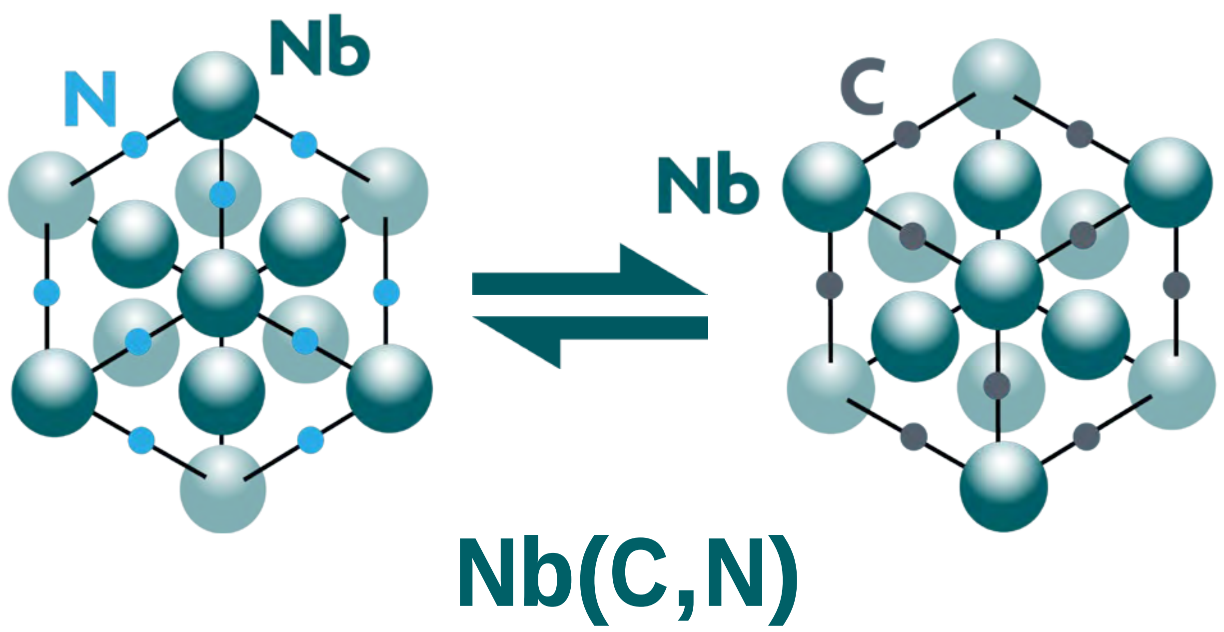


How much Niobium can I use?

- Upon casting, the liquid steel solidifies as it cools. During this process of cooling, the Nb combines with available atoms of Carbon and Nitrogen present to form a precipitate (*i.e. fine particle*) of Niobium Carbo-Nitride, Nb(C,N)

- Importantly, the more Carbon and Nitrogen that is in the steel, the earlier these precipitates will form (*i.e. at a higher temperature*) as the cast cools. Consequently, these precipitates of Niobium with higher Carbon and Nitrogen content are more “stable” at higher temperatures



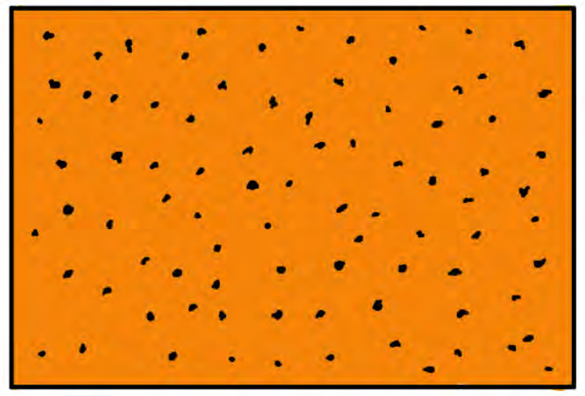


The dissolution of Nb (C,N)

- **Now, for the purpose of using Nb during hot-rolling and making the steel properties we need to have it available in its atomic form, as Nb (***i.e. alone, without the Carbon and Nitrogen***)**

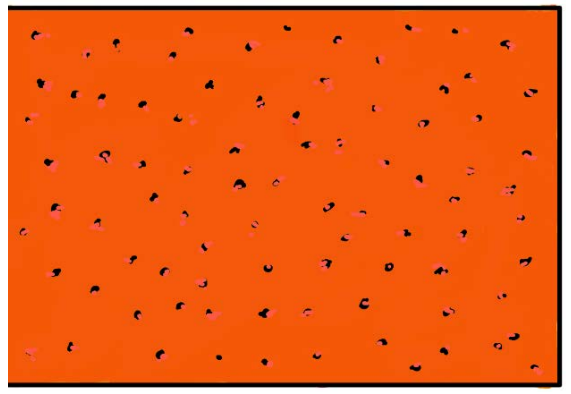
- We can do this through the simple process of reheating the cast slab or billet in a furnace, as we have to do anyway to hot-roll

- At this high temperature we effectively “melt or re-dissolve” this Nb(C,N) precipitate, bringing back Nb into “solution” for us to use



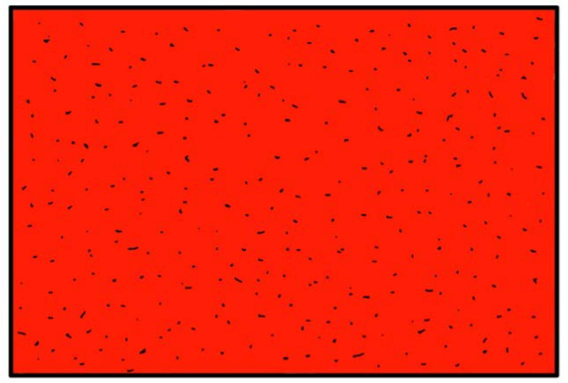
Nb(CN) Precipitates

Reheating 600ºC



Nb(CN) Precipitates

Reheating 1,000ºC



Nb atoms in solution

Reheating 1,150ºC

The dissolution of Nb (C,N)

- The temperature at which this "dissolution" process occurs depends on when these precipitates were originally formed, and this is dependent on the Niobium, Carbon and Nitrogen content (*as discussed earlier*)

- To help us work out what this temperature is we can use one of several published "solubility products" (*i.e. equations*) from the literature. This allows us to calculate the temperature required to bring into solution a given Niobium content with a given Carbon and Nitrogen content

The solubility product of Nb (C,N)

- **It is important to know that there are several solubility products for Nb(C,N) published in the literature. As they all have been established through investigating different steels and analytical techniques, each one gives a slightly different answer!**

- One of the most used “solubility product” is that published by Irvine *at al*. (1967) where [x] is the element content in wt.% and T is temperature in Kelvin:

$$\mathrm{Log}\,[Nb]\,[C + {}^{12}/_{14}\,N] = 2.26 - 6770 / T$$

The solubility product of Nb (C,N)

- There are others in the literature of similar format that are equally acceptable *(see references at end)*

- Within all these equations, it is the Carbon content (not Nitrogen) along with the Niobium that has the largest influence (dominate role) on determining the final dissolution temperature

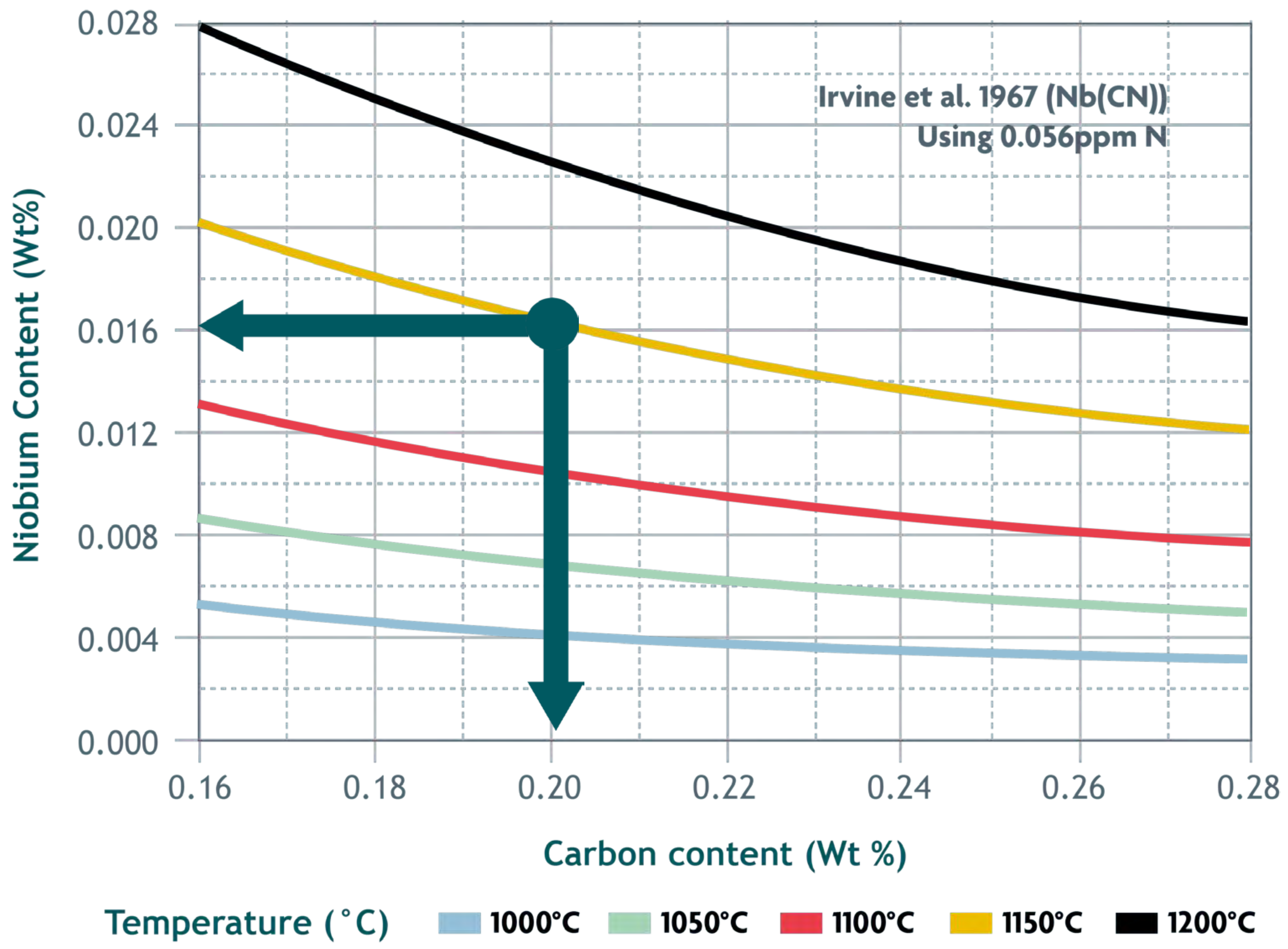
$$\mathrm{Log}\,[\overline{\underline{Nb}}]\,[\overline{\underline{C}}+{}^{12}/_{14}N] = 2.26 - 6770 / \overline{\underline{T}}$$

The solubility product of Nb (C,N)

- We can take this solubility product (*equation*) and easily re-arrange it to work out how much Niobium will go into solution at a given temperature and Carbon content (whilst assuming a fixed Nitrogen level)

- This is shown graphically with iso-temperature lines

- **So in this example: at 0.20%C we should be able to introduce 0.016%Nb into solution by reheating to 1,150°C**



Summary

How much Nb can I use?

Find the Carbon and Nitrogen content of the steel

What is my Reheating temperature ?

What is the core temperature of the cast slab or billet *drop-out or discharge* temperature from the furnace ?

Select an appropriate solubility product equation for Nb(C,N) from the literature to apply

Calculate

Caution: solubility product of Nb(C,N)

- It is important to remember that these solubility products provide only an approximate guide
- In most cases, the bulk composition is used to calculate the dissolution temperature of a precipitate in austenite. However, many precipitate reactions are governed by a local composition rather than a bulk composition
- Hence, the influence of segregation on precipitation must be considered when applying any solubility equation
- Solubility products can be influenced by the presence of elements that do not directly participate in the precipitation reaction
- For example, the addition of other elements into the steel such as Titanium will also influence the dissolution behaviour. Furthermore, some researchers have also shown the influence of elements such as Manganese and Silicon too

Useful references

The following provides some useful references for further information:

- K.J. Irvine, F.B. Pickering and T. Gladman, J. Iron Steel Inst., 205 (1967), 161-182
- T. Gladman, The physical metallurgy of microalloyed steels, 1st ed., The University Press, Cambridge 1997
- E.J. Palmiere, Proc. of Inter. Conf. Microalloying ‘95, Iron and Steel Soc., Pittsburgh, 1995, 307-320
- R.C. Hudd, A. Jones and M.N Kale, J. Iron Steel Inst., (2) (Feb. 1971), 121
- S. Koyama, T. Ishii and K. Narita, J. Jap. Inst. Materials, 35 (11) (1979), 1089-1094
- A.J. DeArdo, M. Hua and C.I. Garcia, Automotive Symposium, Araxá, Brazil, Ed. By TMS, 2005

Niobium, grams saving tonnes