The need for Pre-Heating when Welding

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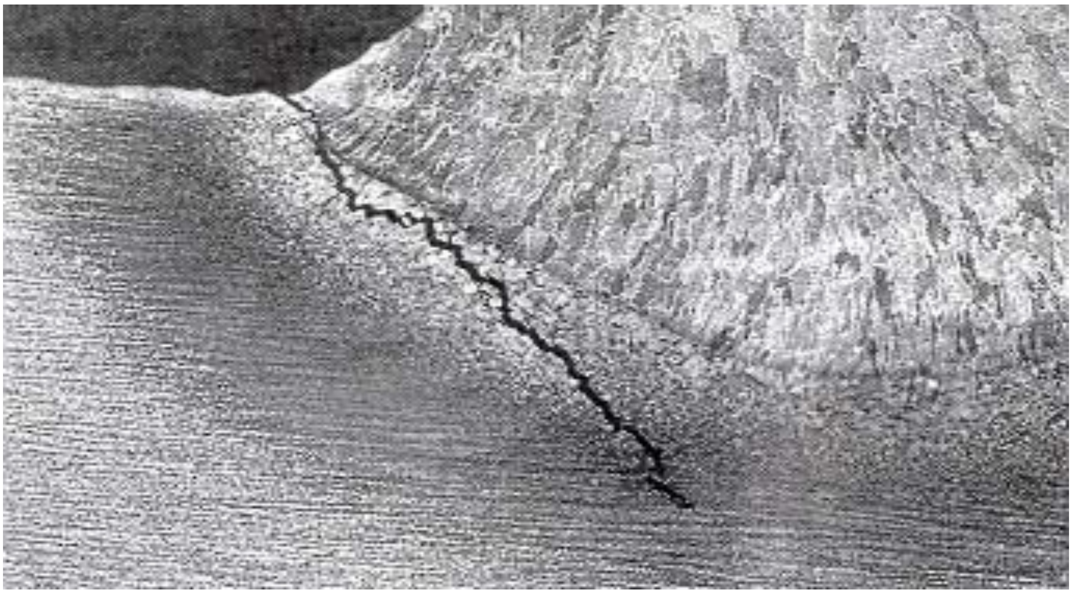
Why do some steels need pre-heating before welding and some don't? To what temperature level do one need to bring the steel before welding? This article seeks to give answers and guidelines to these questions.

What is the purpose of pre-heating?

1) Reduce the risk of hydrogen cracking

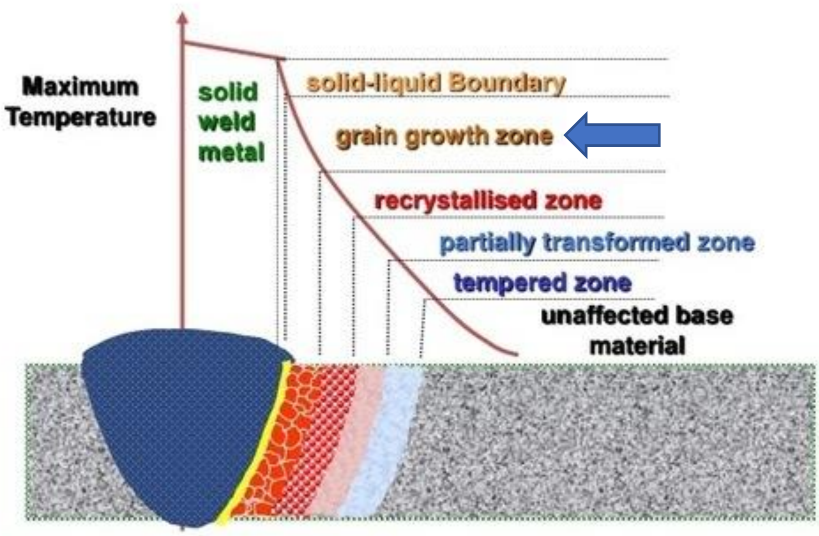
Hydrogen is a very searching gas that can be liberated by oil, grease, rust etc. and water under the certain conditions. The greatest risk comes from hydrogen generated within the arc from damp or contaminated welding consumables, mainly fluxes or electrode coatings. Hydrogen will form into hydrogen porosity in the welds heat effected zone as the weld solidify. Given the right conditions it can develop into hydrogen cracks also referred to as cold cracks.
Contamination on the parent metal can also be a risk unless the heat from the welding arc can drive it away. Moisture from condensation on the parent metal will normally be removed by the heat from the arc before it can get into the weld pool. A hydrogen crack can take anything from a few hours to 24 hours to occur. After 24 hours cracking is still possible but less likely, although there have been some reported cases of cracking at 72 hours. It is therefore good practice to allow at least 48 hours before carrying out any NDT (Non-Destructive Testing). Hydrogen will eventually disperse from the parent metal, within a few days at room temperature or a few hours if held at around 200°C (392°F). Hydrogen cracking is only possible at room temperature, this is why it is also referred to as cold cracking.



2) Reduce the hardness of the weld Heat Affected Zone (HAZ)

A hydrogen crack requires a hard microstructure which is created by a harden able material subject to fast cooling from 800°C(1472°F) to 500°C(932°F). These cracks form in the coarse-grain growth zone in the Heat Affected Zone (HAZ). The hardened structure will normally be martensite. This is a very hard form of steel crystalline structure. Cooling can be slowed down by applying preheat. Other factors that can help, is maintaining a high interpass temperature (base materials temperature during welding). This will normally be done by increasing welding amperage and reducing travel speed.

Heat affected zone (HAZ)



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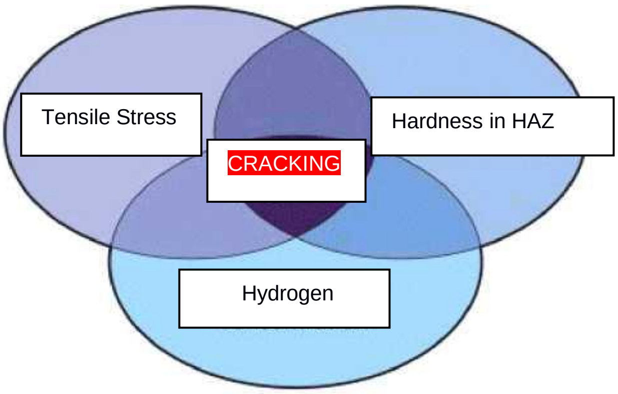
3) Reduce shrinkage stresses during cooling and improve the distribution of residual stresses.

The heat developed during welding will result in expansion and contraction. The result can be distortion or stress build-up or a combination of the two. When a hot weld bead cools, it shrinks more than the surrounding cooler metal and thus is strained severely – sometimes so severely that the weld cracks. The more massive the joint, the more strain occurs in the weld bead. If the base metal around the joint is preheated, the base metal and the weld metal shrink more uniformly as the joint cools. This is usually helpful because less strain occurs in the weld bead and weld cracking is less likely to occur. Tensile stress is something one can influence by applying a weld sequence that do not produce very high tensile stresses in the welded joint. Avoid starts and stops in the corners of welded joints. Eliminate wide gaps in the joint. Gaps should preferably be less than 3 mm (1/8") wide. Weld from sections with the highest restraint towards sections with lower degrees of restraint. Back-step welding techniques can be used and should be preferred.

If all 3 factors are present there is a strong likelihood for cracking to develop after welding.



We should therefore aim towards removing or reducing the above factors to avoid cracking.

How to calculate pre-heating temperature

Factors which influence the need for pre-heating and reduce the risk of hydrogen cracks are:
Chemical composition of the steel
Material thickness
Joint configuration
Ambient temperature, Cooling rate
Hydrogen content of the weld metal/ consumable

Welding method/ Welding technique will to a lesser extent influence on the pre-heating temperature. They will on the other hand be of significant importance when it comes to heat input during welding and thereby the interpass temperature.

Chemical composition of the steel
The hardening of a carbon manganese steel/low alloy steel is influenced primarily by carbon content and to a lesser extent other constituent such as manganese, chrome, silicone etc.
The Carbon Equivalent (CE) is a formula used to express the harden-ability of a particular alloy steel in terms of an equivalent plain carbon steel. Several such formula exist, the one favoured for low alloy steel is the IIW formula:

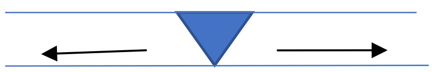
$$CE_{IIW} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

The % of Carbon (C) + % Manganese (Mn) divided by 6 + % Chromium (Cr) + % Molybdenum (Mn) + % Vanadium (V) divided by 5 + % Nickel (Ni) + % Copper (Cu) divided by 15

Depending on the result of the calculation we can give the following recommendation for consumable and pre-heating temperature:

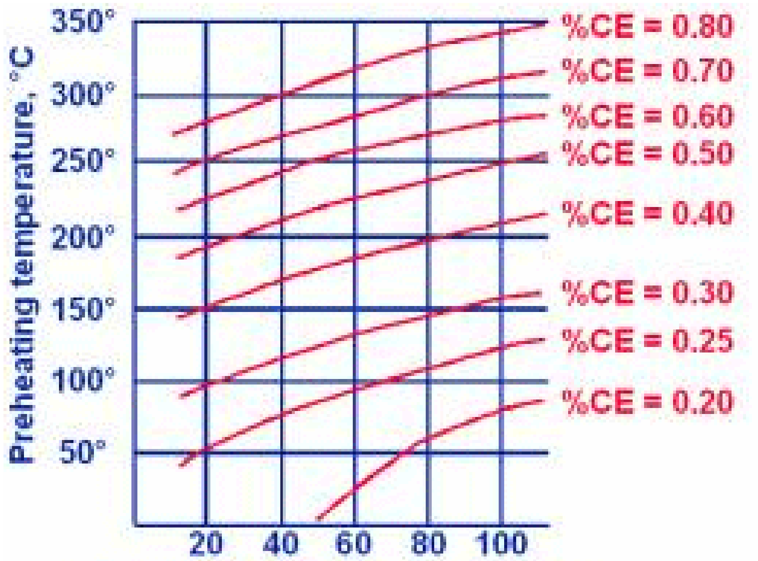
Carbon Equivalent CE	**Welding conditions**
0,35- 0,48	**Can be welded with** **a) Rutile electrodes if base material is kept at 100-200°C (212-392°F)** **b) Basic coated low hydrogen electrodes**
0,48- 0,55	**Can be welded with** **a) Basic coated low hydrogen electrodes if base material is kept at 200- 370°C(392-698°F)** **b) Austenitic electrodes**
0,55 and above	**Can be welded with** **a) Basic coated low hydrogen electrodes if base material is kept at a very high temperature** **b) Austenitic electrodes**

Chemical composition of the steel is however not sufficient to determine the pre-heating temperature. **Material thickness** and **Joint configuration** is also important for finding the correct temperature. Remember that the surrounding base material to the weld zone will work as a heat sink rapidly removing the heat thereby increasing the cooling rate of HAZ.



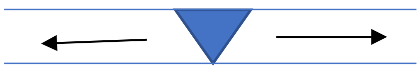
The thicker the base material the faster the rate of heat being transferred from HAZ. We therefore also have to take Material thickness into consideration.

Pre-heating temperature depending on CE and material thickness

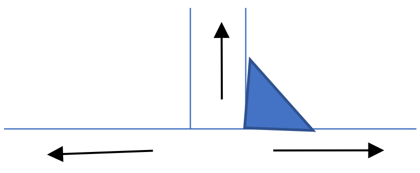


Combined Thickness of workpiece in mm

We have so far stressed the importance of considering **chemical composition** and **material thickness**. Another factor is **Joint configuration**. In our above example we looked at a butt joint where the heat can escape in two directions. What if the heat can escape in more directions? The cooling rate in HAZ will obviously be faster. The heat sink caused by the parent metal thickness and the number of available paths the heat can take to escape, will influence cooling rate. (However, once the heat sink reaches a certain size, further increases have a negligible effect on cooling rate.). This is why when determining preheat the term **combined thickness** is used, for a butt weld it is twice the thickness of the parent material and for a T-fillet weld three times the thickness.



Butt-weld: Twice the thickness of the parent material
Combined Thickness: T X 2



T-fillet weld: Three times the thickness of the parent material
Combined Thickness: T X 3

Ambient temperature:

The occurrence of cold cracking is significantly affected by the ambient temperature. Cracking is more likely at the lower temperatures. So low temperatures mean faster cooling rates which means increased possibility for cracking after welding. As for the determination of preheat at lower ambient temperatures, the following paper should be referred to.
T. Kasuya and N. Yuiroka: "Determination of necessary preheat temperature to avoid cold cracking under various ambient temperatures", ISIJ International, vol. 35 (1995), No.10, p.1183-1189

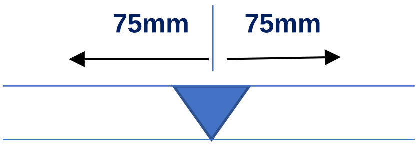
Preheating method:

Onboard vessels one will in most cases have access to preheating by an oxygen acetylene torch. Propane is for safety reasons not recommended. Preferably make use of big size 2500 L or 5000 L multiflame torches.

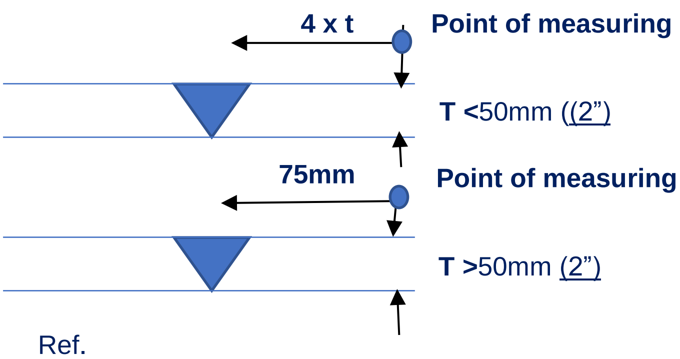
Techniques for measuring the temperature can be Crayons/ Temperature sticks.

For more accurate pre-heating and whenever there is a procedure requirement electric preheating equipment will come to use. This type of equipment will also be able to record and document the preheating cycle.

Minimum pre heat temp to be established at a distance no less than 75mm (3”) in all directions from point of welding.



The objective of preheating is to enhance the hydrogen evolution from a weld. The effect of preheating increases as the width of preheating increases and the heating rate of preheating decrease. The preheating width over 200mm (8”) each side of the groove is desired.



Ref.
BS EN ISO 13916:1997
Welding: Guidance on Pre-heating, Interpass temp.

Hydrogen content of the weld metal/ consumable

Carbon Equivalent (CE) and material thickness are essential parameters in order to find the correct preheating temperature. It is of equal importance to make absolutely sure that the correct consumable is selected for the job at hand. All electrode coatings are hygroscopic (they absorb moisture from the atmosphere). When welding, the moisture turns into hydrogen in the arc that again ends up as hydrogen porosity in the weld deposit. Combined with effects like the already mentioned high CE and material thickness in combination with shrinkage stresses can therefore result in hydrogen cracking/ cold cracking.

If properly stored, transported and used, basic coated low hydrogen electrodes will form weld deposits with low hydrogen content. If not, hydrogen porosity can lead to hydrogen cracking also for this type of electrodes.

By following the recommended storage, and procedures for handling and re-drying, the moisture level in electrode coatings can be minimised, along with the associated risk of cold cracking.

Hydrogen levels are measured as ml H2/100 g (Millilitre Hydrogen per 100 gram) weld deposit. Typical hydrogen levels for different electrode coating types are as follows:

Rutile and Acid electrodes >15 ml/100 g
Basic low hydrogen electrodes < 10, < 5 and < 3 ml/100 g

Recommended storage, and procedures for handling

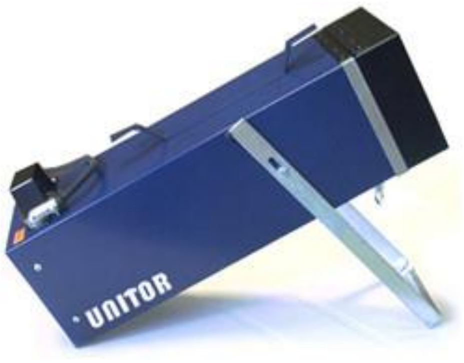
Welding consumables should be stored in their original packing. As a guideline we recommend the following temperatures in the storage room:

Temperatures °C (°F)	Max Relative humidity in %
5–15 (41–59)	60
15–25 (59–77)	50
Above 25 (77)	40

During the winter, it is possible to maintain low relative humidity by keeping the temperature in the store- room at least 10 °C (50 °F) above the outdoor temperature. During certain periods in the summer and in a tropical climate, sufficiently low relative humidity can be maintained by air de-humidification. The purpose is to avoid hydrogen absorption as much as possible.

Basic low hydrogen electrodes are normally re-dried at a temperature of around 350 °C (662°F) for 2 hours, to achieve a hydrogen level of 5–10 ml/100 g. (BS 5135, Scale C). Re-drying should be restricted to a maximum of 3 cycles.

To achieve extreme low hydrogen levels, <4.0 ml/100 g, a re-drying temperature of 400 °C (752°F) is recommended for 1–2 hours. Re-drying should be restricted to 1 cycle.



Portable Mini-dryer that connects to 230V 1 phase and operating from 100- 350°C (212-662°F)

Re-dried basic electrodes can be stored in a heated cabinet at 80°C (176°F) without further moisture pick-up.

In order to extend the electrodes usable lifetime and safeguard against cold cracking, some electrode manufactures deliver electrodes with Low Moisture Absorption properties. This greatly reduces the electrodes moisture absorption rate. One can also purchase basic coated low hydrogen electrodes in vacuum packing something that further secure quality.

NB. Never pre heat stainless steel.
For T1 steel (Manganese steel used in for example earth excavating equipment), one must be very carful with regards to pre-heat and interpass temperature. Depending on how massive the joint the combined pre-heat and interpass temperature can range from 70 to 200°C (158-392°F).

A practical example

In order to secure the cargo, sea fastening brackets are to be welded to the deck and you need to determine pre-heating temperature. Configuration and dimensions as below;

Base material (all parts):
C: 0,15 - Si: 0,35 - Mn: 1,46 – Cr: 0,02 – Ni: 0,02
Deck plate 20mm (25/32”)
Bracket 15mm (19/32”)
Forming a T-fillet weld
Determine pre-heating temperature.

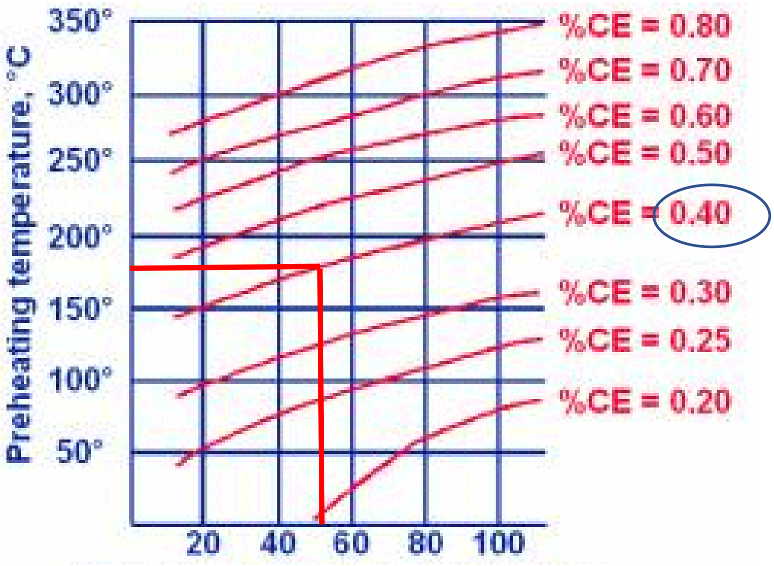
$$CE_{IIW} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

CE = 0,15 + (1,46: 6) + (0,02: 5) + (0,02: 15)

CE = 0,40

Combined thickness= 20mm (25/32”) +20mm (25/32”) +15mm (19/32”)

Combined thickness= 55mm (2 11/64”)



Combined Thickness of workpiece in mm

Pre-heating temperature: 175°C (347°F)