# Preheating of Materials

## What is Preheat?

A heating procedure applied to parent metal components immediately before welding commences, and considered as an essential part of the welding operation, is called 'Preheat'.

Preheating can be applied locally to the areas to be welded, or to the whole component. It is usually done to raise the temperature of the weld area so that the weld does not cool too quickly after welding. This protects the material being welded from the various adverse effects that can be caused by the normally rapid cooling cycle created by the welding process.

Note that, while preheat is applied before welding begins, it is essential that the minimum preheat temperature is maintained throughout the welding operation.

### What does Preheat do?

Basically, preheat puts the parent metal components in a suitable condition for the subsequent welding operation. Preheating may be carried out for any of the following reasons;

- Slow down the cooling rate
- Reduce shrinkage stress and weld distortion
- Promote fusion
- Remove moisture

### Slow Down the Cooling Rate

Some alloys (notably high carbon and low alloy steels), if welded and allowed to cool quickly, can develop hard or brittle phases in the heat affected zone (HAZ). These phases can render such alloys susceptible to cracking under the action of tensile shrinkage stresses as the weld area cools down, or they can result in low toughness of the HAZ.

Many steels are susceptible to hydrogen cracking, and fast cooling rates not only promote the formation of hard, susceptible microstructures but also lock the hydrogen into the solidifying weld metal. Because of this trapped hydrogen gas, pressure builds up in the weld and the heat affected zone, which can result in cracking of the already brittle microstructure. Such cracks are normally detected by post-weld inspection techniques, but should they escape detection, they may lead to premature failure in service, with potentially disastrous consequences.

Preheating of components prior to welding in these situations is designed primarily to slow down the rate of cooling of the weldment. In reducing the cooling rate, preheat is protecting the parent metal by helping to prevent hardening of the weld by the formation of brittle phases. A softer, more ductile structure is more resistant to cracking. The slower cooling rate also gives more time for any hydrogen introduced into the weld to diffuse away from the welded joint.

### Reduce Shrinkage Stress and Weld Distortion

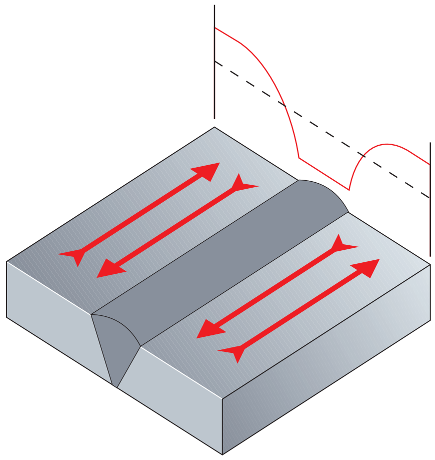
If welds are made in highly restrained joints, or in materials with very low ductility (e.g. cast irons), the welding cycle of heating, followed by rapid cooling, can result in cracking in the weld or the surrounding area. This is due to the weld metal or adjacent parent metal not being able to withstand the effects of shrinkage stresses created by contraction.

### Metals and alloys that should not be preheated

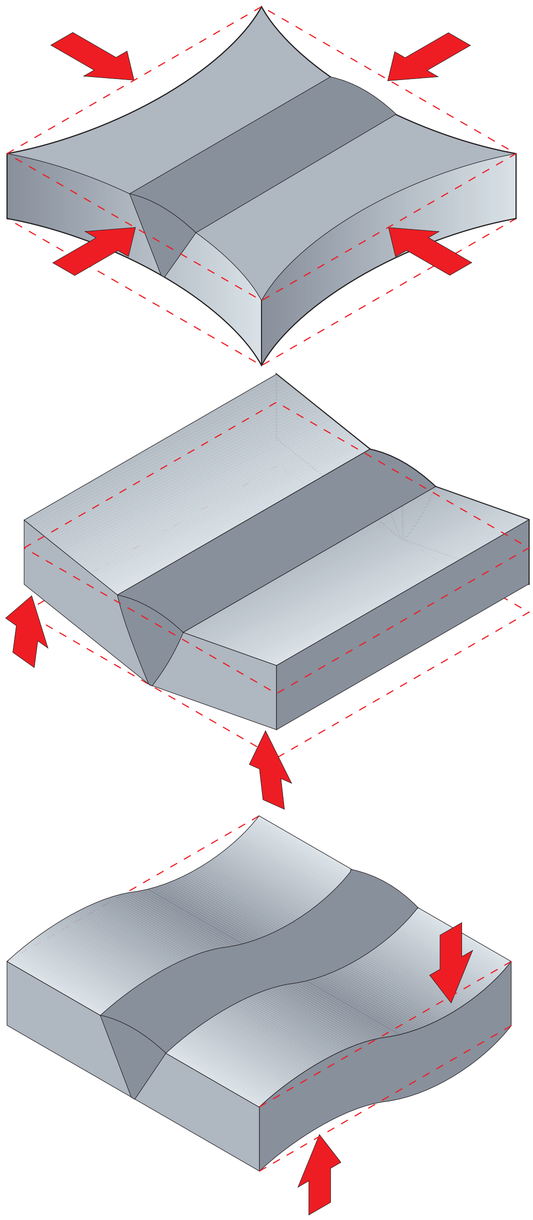
Preheat and high interpass temperatures can have a negative effect on the mechanical properties or corrosion resistance of some alloys. For example:

- Austenitic manganese (13% Mn) steel
- Austenitic stainless steels
- Duplex stainless steels
- Titanium alloys*

* For further information, please consult your local BOC Welding Specialist, BOC Technical Manager or Welding Engineers.



*Residual stresses present in a welded joint.*



*Distortion due to the presence of residual stress*

Here preheating is used to balance the thermal cycle and so reduce the shrinkage stresses in the weld and in the adjacent parent material.

When welding wrought materials in highly restrained joints, preheat is normally applied locally in the weld area.

When welding castings, the preheat applied may be 'local' (heating in the area of the weld only), 'total' (the whole casting is heated), or 'indirect' (heating a part of the casting away from the weld area to balance the effects of expansion and contraction).

### Promote fusion

Some alloy systems (e.g. copper and aluminium) have very high thermal conductivity, and if a weld is attempted on thick, cold plate, the parent material could chill the deposited weld metal so quickly that it does not fuse with the parent metal. This may be referred to as a 'cold start'. The heat conduction away from the joint area can be such that a weld may be impossible using a conventional arc welding process.

Preheat is used in this case to raise the initial temperature of the material sufficiently to ensure full weld fusion from the start. This is particularly important when using a welding process / plate thickness combination that is likely to produce a cold start.

### Remove Moisture

Any metallic components left overnight in a cold workshop or brought in from outside are likely to be damp or even wet. If they are welded in that condition, problems can arise in the resultant welds. For example, if the components are made of steel, then the moisture will act as a source of hydrogen and the result could be hydrogen cracking. Aluminium has a porous oxide layer, which will absorb moisture from the atmosphere, and, if not removed before welding, this can result in weld metal porosity and subsequent rejection of the weld.

While not normally the main objective of preheating, its use for removal of surface moisture prior to welding is not only advisable, but very often essential.

## Carbon Steel and Alloy Steel

These two groups of materials have, quite rightly, been given more attention in estimation of preheat temperature than any other alloy system, as the penalty for getting it wrong can be severe.

The following list is intended only to give some indication of the level of preheat required for certain types of steel. In these examples, it is assumed that the weld is a butt weld, and the thicknesses given are the normally used 'combined thickness', where this is the total thickness of all the parts to be joined.

When calculating the 'combined thickness' of parts with varying thicknesses (such as forgings), the thickness of each part is usually averaged over a distance of 75 mm from the weld line. However, for some processes and materials, account must be taken of any difference of thickness beyond the 75 mm point, and it is important to refer to the specific welding procedures or relevant standards in each case.

| Steel type | Combined Thickness (mm) | Typical Preheat (°C) |
|---|---|---|
| Low C and mild steels | <50 | ≤50 |
| | >50 | 100–150 |
| Medium C, C-Mn steels | <40 | 100–200 |
| | >40 | 150–250 |
| High C, C-Mn steels | All | 200–300 |
| QT steels, HSLA steels | All | None to 150 (max.) |
| 0.5% Mo, 1% Cr-0.5% Mo steels* | All | 100–250 |
| 2% Cr-1% Mo, 5% Cr-0.5% Mo steels* | All | 200–300 |
| Direct hardening steels | All | 150–300 |
| Case hardening steels | All | 150 |
| 13% Manganese steel | All | None |

*Preheat is usually specified by procedure and tightly monitored and controlled with these materials.

It is recommended that more comprehensive documentation be consulted when selecting a temperature for a specific application.

Information to assist with calculation of preheat for C-Mn steels can be found in international standards (e.g. BS 5135, AWS D1.1 and AS/NZS 1554.1). These standards set out minimum preheat temperatures based on factors such as the type of steel specification or carbon equivalent, thickness, the welding process or heat input, and the hydrogen class of the welding consumable. The guidelines do not take restraint into consideration, so highly restrained joints may need higher levels of preheat than indicated.

The information in these standards is often used as a rough guide to determine preheat for low alloy steels. This should be done with extreme caution, as low alloy steels will frequently need much higher preheat than estimated by this means because of their alloy content.

When joining or surfacing hardenable steels (steels with high CE), it is sometimes possible to weld with an austenitic type consumable and to use a lower preheat than would be needed if ferritic consumables were to be used.

The decision-making process, when deciding whether to use preheat with carbon steel and alloy steel, can become quite complicated. Carbon and carbon-manganese steels and low alloy steels may require preheating, but this depends on their carbon equivalent, combined thickness and proposed welding heat input.

Preheat with these ferritic materials is primarily aimed at reducing the severity of the 'quench' after welding, and helping to prevent the formation of hard brittle microstructures in the weld and HAZ. It also allows hydrogen to diffuse away from the weld area, thus reducing the risk of hydrogen cracking. The objective is to keep the maximum HAZ hardness to below about 350 Hv, although this will not always be possible, particularly with some low alloy steels with high hardenability. These low alloy types may, additionally, need a post-weld heat treatment to restore properties.

### How much Preheat to Apply

The actual preheat temperature required for a specific welding operation depends not only on the material or materials being welded, but also the combined thickness of the joint, the heat input from the welding process being used, and the amount of restraint imposed upon the components. There are no hard and fast rules regarding how much preheat to apply, but there are many publications available that give helpful guidance. These publications include national and international standards or codes of practice and guides from steel and aluminium alloy producers and from consumable manufacturers. Some guidelines are included here and, as in the previous section, categorised for convenience by alloy type.

## Preheating of Aluminium and Aluminium alloys

### When to Preheat

Preheat is needed when there is a risk that, if a welding operation is carried out 'cold', an unsound weld could be produced. While it is not possible here to cover all eventualities, there are certain guidelines that can be followed in making the decision as to whether to preheat or not, and these are outlined here, categorised for convenience, by alloy type.

### Aluminium Alloys

Aluminium Alloys have a high thermal conductivity and preheat is used to provide additional heat to the weld area to help ensure full fusion of the weld. Application of preheat is also used to drive off any moisture in the surface oxide. Preheating is not necessary when welding thin sheet, but becomes increasingly important as thickness increases. High conductivity aluminium busbars are a prime example.

As a rule, aluminium alloys are only preheated to temperatures between 80–120°C. Certain heat treatable aluminium alloys (Al-Si-Mg) are sensitive to HAZ liquation cracking if overheated, and preheat must be carefully controlled within this range. With less sensitive alloys, preheat may be increased up to a maximum of 180–200°C. Remember that aluminium alloys have relatively low melting points and care must be taken to avoid overheating, which can result in poor weld quality and cracking in some alloys.

## Preheating of Stainless Steel

Martensitic stainless steels generally require preheating to 200–300°C, depending on carbon content plus post-weld heat treatment to prevent cracking in the weld and/or HAZ. This applies whether they are welded with matching consumables or, as is quite common, with austenitic consumables.

Some ferritic stainless steels should be preheated to about 200°C to prevent embrittlement. They may also need a post-weld annealing treatment, depending on application.

Should it be necessary to preheat duplex stainless steel, it is normal to keep it fairly low, up to a maximum of 150°C for 'Duplex' and 100°C for 'Super Duplex'. Preheat is invariably specified by procedure and tightly monitored and controlled with these materials.

No preheat at all is required when welding austenitic stainless steels.

## Preheating of Copper and Copper Alloys

High conductivity copper, phosphorus de-oxidised (PDO) copper and many of the leaner copper alloys have high thermal conductivities and consequently need a very high preheat to ensure full fusion of the joint.

Those high conductivity copper alloys that require preheating before welding are normally heated to temperatures of 600–700°C.

Bronzes and brasses, on the other hand, are normally welded without preheat. Their thermal conductivity is low enough to allow full fusion to be readily achieved, and some alloys suffer from 'hot shortness' and so need to cool relatively quickly after welding to avoid cracking. Any applied preheat would prolong this cooling period and so render them more liable to crack.