Heat Input & Interpass temperature during welding

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One definition of “welding “goes like this: “Welding is control of heat”.

In the previous article “The need for Pre-Heating when Welding” we informed why some steels need pre-heating before welding and to what temperature level. In this new article we take it all one step further and look at the total heat input and interpass temperature during welding and what effect it will have on the final result.

In a practical welding situation onboard a vessel one can face restrictions towards the heat developed to produce a weld given as a minimum or maximum Heat input and/or a specified interpass temperature.

HEAT INPUT CALCULATION

Total heat input during welding is the heat developed from the welding process (the electrical/combustion energy supplied by the welding arc/flame to the workpiece) and possibly the pre-heating, if the base material so requires.

Heat in the form of an arc or a flame is necessary in order to melt the base material and any consumable during the welding process. The most important characteristic of heat input is that it governs the cooling rates in welds and thereby affects the microstructure of the weld metal and the heat-affected zone. A change in microstructure directly affects the mechanical properties of welds. Therefore, the control of heat input is very important in welding in terms of quality control.

There are several ways of calculating the energy put into a weld. The most common approach to calculating the heat is to use the welding current, voltage and travel speed. An American system for this is given in ASME IX and various AWS standards, and a European system is given in EN ISO 1011-1 and PD ISO/TR 18491.

Both calculations call the energy put into a weld the "heat input", but the European system for calculating heat input differs from the American system by the additional parameter of "thermal efficiency/process efficiency/arc efficiency". Note, in the earlier standard, BS 5135, the heat input was referred to as "arc energy" and did not necessarily include the process efficiency. You may also hear the ASME IX heat input referred to as arc energy under the European system. Ensure all parties agree on the definition (and calculation)

So, to conclude: Arc energy is the energy supplied by the welding arc to the workpiece before the efficiency of the welding process is considered.

The two calculations are:

$$\text{EN Heat input} = \frac{\text{Arc voltage * Arc current * Thermal efficiency}}{\text{Travel speed}}$$

$$\text{ASME/AWS Heat Input} = \frac{\text{Arc voltage * Arc current}}{\text{Travel speed}}$$

Heat input is typically given in kJ/mm, so it is necessary to convert the values to standard units, that is: Current (Amps), Voltage (Volts), Travel speed (mm/s) and Thermal efficiency (no units but is sometime referred to as process efficiency ***η***)

Those units will give the value of heat input in units of J/mm, so dividing the value by 1000 will give it in units of kJ/mm.

Other possible aspects of the calculation are to use a travel speed in mm/min, which requires multiplying the result by 60 or inch/min, which again requires a 60x multiplication factor and will produce a heat input result of kJ/inch.

The thermal efficiency values for the different processes are given in the table below:

Welding Process	Efficiency factor ***η***
Submerged Arc Welding (Under powder)	1.0
Manual Metal Arc Welding (MMA)	0.8
Cored Wire Welding/Flux Cored Arc Welding (FCAW)	0.8
Metal Active Gas (MAG) Metal Inert Gas (MIG)	0.8
Tungsten Inert Gas (TIG)	0.6

Example:

I'm doing Manual Metal Arc Welding (Electrode / stick welding).

My Amperage is 120 Amp, Arc voltage 30 Volt, Welding speed 150mm/min

$$\text{EN Heat input} = \frac{\text{Arc voltage * Arc current * Thermal efficiency}}{\text{Travel speed}}$$

$$\text{EN Heat input} = \frac{30\text{V} * 120\text{A} * 0.8\ \eta}{150\text{mm/min} : 60\text{sec}}$$

EN Heat input = 1152 J/mm : 1000 = 1,15 kJ/mm (28,8 kJ/inch) kJ = kilo Joule is quantity of heat

Heat input is mainly influenced by the travel speed that again depend on welding position.

The following are general principles:

1. Vertical-up progression tends to give the highest heat input because there is a need to weave to get a suitable profile and the forward travel speed is relatively slow.

1. Vertical-down welding tends to give the lowest heat input because of the fast travel speed that can be used.

2. Horizontal-vertical welding is a relatively low heat input welding position because the welder cannot weave in this position.

3. Overhead welding tends to give low heat input because of the need to use low current and relatively fast travel speed.

4. Welding in the flat position (downhand) can be a low or high heat input position because the welder has more flexibility about the travel speed that can be used.

Of the arc welding processes, TIG and MIG/MAG can produce very low heat input.

Typical heat input values for controlled heat input welding will tend to be ~1.0-~3.5kJ/mm.

Cold cracking is a matter of concern only when heat input is less than 3 kJ/mm.

When welding low alloyed steel, the heat input should be approx. 2,5 kJ/mm.

For stainless steel of the 300 series (for example AISI 316L) the heat input should preferably be below 1,5 kJ/mm.

INTERPASS TEMPERATURE

In multipass welds, the interpass temperature is the temperature of the weld zone between consecutive weld passes. The interpass temperature can be specified as a minimum, a maximum, or both, depending on the material being welded.

The minimum specified interpass temperature is typically equal to the minimum specified preheating temperature.

The purpose of maintaining the weld temperature above minimum between passes is the same as that for preheating, to reduce or eliminate the risk of cold weld cracking. Apart from specifying a minimum interpass temperature, a maximum interpass temperature is sometimes specified to ensure that adequate weld properties are obtained. In this case, the steel must be below this temperature before welding continues. Minimum interpass Temperature and minimum pre-heat temperature is the same.

Maximum Interpass temperature:

For many plain carbon steels, such as A36, with thickness less than 19mm (3/4”), the maximum interpass temperature is not critical. EH36 is a steel typically used for shipbuilding applications and the maximum interpass temperatures shall not exceed 200°C (392°F) for thicknesses up to 40 mm (11/2 in) inclusive, and 230°C (446°F) for greater thicknesses. For steel higher interpass temperatures will generally provide a finer grain structure and improved Charpy V notch toughness transition temperatures. However, when interpass temperatures exceed approximately 260°C (500°F), this trend may be reversed.

Where max interpass temperature is most important to keep inside:

Austenitic stainless steel of the 300 series do not harden by heat treatment. This means that no austenite to martensite transformation takes place during cooling from the weld temperature to room temperature. The absence of martensite transformation removes the need for preheating and controlling minimum interpass temperature, since there is no risk of cold cracking. It is important, however, to define and keep below the maximum interpass temperature in order to avoid the loss in corrosion resistance (sensitization).
Maximum interpass temperature for Austenitic stainless steel of the 300 series (for example AISI 316 L) and nickel-base alloys should therefore be kept at max 150°C (300°F). Weld temperature between passes should be controlled so as not to exceed this temperature, in order to retain the corrosion resistance of the stainless steel.

Controlling max interpass temperature not exceeding 150°C (300°F) is also important in quenched and tempered (Q & T) steels.
This temperature limit should also be observed for the 13% Manganese steel. Exceeding maximum interpass temperature in these steels can have adverse effects on strength, toughness and fracture toughness.

For Aluminium alloys in general in order to prevent hot cracks keep interpass temperature at 70°C (158°F).

For aluminium alloy 5XXX, maximum interpass temperature 65°C (150°F) to avoid cracks.

Aluminum alloys with 3.5 - 5.5 Mg do not exceed 120°C (248°F) in order to prevent cracking.

There are a number of copper alloys. Here are listed the interpass temperature for the most common alloys:

Copper-Zinc alloys (Brass): 260 to 370 °C (500 to 698°F)

Copper-Tin alloys (Phosphor Bronzes): Not to exceed 200°C (392°F)

Copper-Nickel alloys: Maintain below 65°C (149°F)

Aluminium-Bronze: Should be limited to 150°C (300°F)

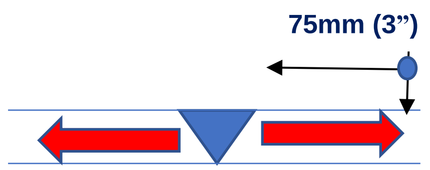
CONTROL AND MEASURING INTERPASS TEMPERATURE

Accepted method of controlling the interpass temperature is to use two temperature indicating crayons.
A surface applied temperature indicating crayon (often referred to by the trade name Tempilstik) melts when the material to which it is applied reaches the crayon's melting temperature.
The crayons are available in a variety of melting temperatures, and each individual crayon is labelled with its approximate melting point.
One temperature indicating crayon is used to measure the minimum specified interpass temperature, while the second is a higher temperature crayon used to measure the maximum specified interpass temperature (if required).
If pre-heating is required the welder first heats the joint to be welded and checks the base metal temperature at the code-designated location by marking the base metal with the first temperature indicating crayon.
When the minimum specified preheat temperature is reached (when the first crayon mark melts), the first welding pass can commence.

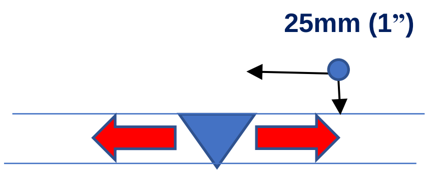
Immediately before the second and subsequent passes, the minimum and maximum (if specified) interpass temperature should be checked in the proper location.
The lower temperature crayon should melt, indicating that the temperature of the base metal is greater than the melting temperature of the crayon, while the higher temperature crayon should not melt, indicating that the base metal temperature is not above the maximum interpass temperature.
If the lower temperature crayon does not melt, additional heat in the form of welding should be applied to the joint until the crayon mark on the base metal melts.
If the upper temperature crayon melts, the joint should be allowed to slowly cool in the ambient air until the upper temperature crayon no longer melts, while the lower temperature crayon does melt.
Then the next welding pass can begin.

WHERE TO MEASURE

There are codes and industry standards that specify where the interpass temperature is to be checked.
Codes require that the interpass temperature be maintained “for a distance at least equal to the thickness of the thickest welded part (but not less than 75mm (3”) in all directions from the point of welding.
This makes sense and is conservative when controlling the minimum interpass temperature.
However, if maximum interpass temperature is also to be controlled, then the actual interpass temperature in the adjacent base metal may significantly exceed the maximum specified interpass temperature.
If this is the situation, it is more appropriate to measure the temperature 25mm (1”) away from the weld toe.



Minimum Interpass temp
Point of measuring



Maximum Interpass temp
Point of measuring