Welding Job Knowledge

Heat treatment of welded joints - Part 2

Part 1 of this series of articles gave definitions of some of the heat treatments that may be applied to a welded joint and dealt with the operation of stress relieving a ferritic steel assembly. The temperature range within which stress relief takes place will also cause tempering of those regions in the HAZ's where hard structures may have formed.

Tempering

Tempering is a heat treatment that is only relevant to steels and is carried out to soften any hard micro-structures that may have formed during previous heat treatments, improving ductility and toughness. Tempering also enables precipitates to form and for the size of these to be controlled to provide the required mechanical properties. This is particularly important for the creep resistant chromium-molybdenum steels. Tempering comprises heating the steel to a temperature below the lower critical temperature; this temperature being affected by any alloying elements that have been added to the steel so that for a carbon-manganese steel, the temperature is around 650°C, for a 2¼CrMo steel, 760°C . Quenched steels are always tempered. Normalised steels are also usually supplied in the tempered condition although occasionally low carbon carbon-manganese steel may be welded in the normalised condition only, the tempering being achieved during PWHT. Annealed steels are not supplied in the tempered condition.

Tempering of tool steels may be performed at temperatures as low as 150 degrees C, but with the constructional steels that are the concern of the welding engineer the tempering temperature is generally somewhere between 550-760°C, depending on the composition of the steel.

Post Weld Heat Treatment (PWHT)

As mentioned in Part 1, PWHT is a specific term that encompasses both stress relief and tempering and is not to be confused with heat treatments after welding. Such treatments may comprise ageing of aluminium alloys, solution treatment of austenitic stainless steel, hydrogen release etc. PWHT is a mandatory requirement in many codes and specifications when certain criteria are met. It reduces the risk of brittle fracture by reducing the residual stress and improving toughness and reduces the risk of stress corrosion cracking. It has, however, little beneficial effect on fatigue performance unless the stresses are mostly compressive.

It is an essential variable in all of the welding procedure qualification specifications such as ISO 15614 Part 1 and ASME IX. Addition or deletion of PWHT or heat treatment outside the qualified time and/or temperature ranges require a requalification of the welding procedures. PWHT temperatures for welds made in accordance with the requirements of EN 13445, ASME VIII and BS PD 5500 are given below in Table 1.

Table 1: PWHT Temperatures from Pressure Vessel Specifications

Steel Grade	BS EN 13445 Temp range °C	ASME VIII Normal holding temp ˚C	BS PD 5500 Temp range °C
C Steel	550-600	593	580-620
C 1/2 Mo	550-620	593	630-670
1Cr 1/2 Mo	630-680	593	630-700
2 1/4 Cr/Mo	670-720	677	630-750
5CrMo	700-750	677	710-750
3 1/2 Ni	530-580	593	580-620

Note from Table 1 that ASME VIII specifies a minimum holding temperature and not a temperature range as in the BS and EN specifications.

As mentioned above, PWHT is a mandatory requirement when certain criteria are met, the main one being the thickness. BS EN 13445 and BSPD 5500 require that joints over 35mm thick are PWHT'd, ASME VII above 19mm. If, however, the vessel is to enter service where stress corrosion is a possibility, PWHT is mandatory, irrespective of thickness. The soak time is also dependant on thickness. As a very general rule this is one hour per 25mm of thickness; for accuracy, reference must be made to the relevant specification.

These different requirements within the specifications mean that great care needs to be taken if a procedure qualification test is to be carried out that is intended to comply with more than one specification. A further important point is that the PWHT temperature should not be above that of the original tempering temperature as there is a risk of reducing the strength below the specified minimum for the steel. It is possible to PWHT above the tempering temperature only if mechanical testing is carried out to show that the steel has adequate mechanical properties. The testing should, obviously, be on the actual material in the new heat treatment condition.
Maximum and minimum heating and cooling rates above 350-400°C are also specified in the application codes. Too fast a heating or cooling rate can result in unacceptable distortion due to unequal heating or cooling and, in very highly restrained components, may cause stress cracks to form during heating.

Application of PWHT

The method of PWHT depends on a number of factors; what equipment is available, what is the size and configuration of the component, what soaking temperature needs to be achieved, can the equipment provide uniform heating at the required heating rate? The best method is by using a furnace. This could be a permanent fixed furnace or a temporary furnace erected around the component, this latter being particularly useful for large unwieldy structures or to PWHT a large component on site. Permanent furnaces may be bogie loaded with a wheeled furnace bed on to which the component is placed or a top hat furnace that uses a fixed hearth and a removable cover. Typically, a furnace capable of heat treating a 150tonne pressure vessel would have dimensions of around 20m long, a door 5x5m and would consume around 900cu/metres of gas per hour.

Furnaces can be heated using electricity, either resistance or induction heating, natural gas or oil. If using fossil fuels care should be taken to ensure that the fuel does not contain elements such as sulphur that may cause cracking problems with some alloys, particularly if these are austenitic steels or are nickel based – corrosion resistant cladding for example. Whichever fuel is used the furnace atmosphere should be closely controlled such that there is not excessive oxidation and scaling or carburisation due to unburnt carbon in the furnace atmosphere. If the furnace is gas or oil fired the flame must not be allowed to touch the component or the temperature monitoring thermocouples; this will result in either local overheating or a failure to reach PWHT temperature.

Monitoring the temperature of the component during PWHT is essential. Most modern furnaces use zone control with thermocouples measuring and controlling the temperature of regions within the furnace, control being exercised automatically via computer software. Zone control is particularly useful to control the heating rates when PWHT'ing a component with different thicknesses of steel. It is not, however, recommended to use monitoring of the furnace temperature as proving the correct temperatures have been achieved in the component. Thermocouples are therefore generally attached to the surface of the component at specified intervals and it is these that are used to control the heating and cooling rates and the soak temperature automatically so that a uniform temperature is reached. There are no hard and fast rules concerning the number and disposition of thermocouples, each item needs to be separately assessed.

As mentioned earlier, the yield strength reduces as the temperature rises and the component may be unable to support its own weight at the PWHT temperature. Excessive distortion is therefore a real possibility. It is essential that the component is adequately supported during heat treatment and trestles shaped to fit the component should be placed at regular intervals. The spacing of these will depend on the shape, diameter and thickness of the item. Internal supports may be required inside a cylinder such as a pressure vessel; if so, the supports should be of a similar material so that the coefficients of thermal expansion are matched.

Whilst heat treating a pressure vessel in one operation in a furnace large enough to accommodate the entire vessel is the preferred method this is not always possible. In this case the pressure vessel application codes permit a completed vessel to be heat treated in sections in the furnace. It is necessary to overlap the heated regions – the width of the overlap is generally related to the vessel thickness. BS EN 13445 for instance specifies an overlap of $5\sqrt{Re}$ where R = inside diameter and e = thickness; ASME VIII specifies an overlap of 1.5 metres. It should be remembered that if this is done there will be a region in the vessel (which may contain welds) that will have experienced two cycles of PWHT and this needs to be taken into account in welding procedure qualification testing. There is also an area of concern, this being the region between the heated area within the furnace and the cold section outside the furnace. The temperature gradient must be controlled by adequately lagging the vessel with thermally insulating blankets and the requirements are given in the application codes.

It is, of course, possible to assemble and PWHT a vessel in sections and then to carry out a local PWHT on the final closure seam. Local PWHT will be discussed in the next part of this series on heat treatment.

Part 3 will cover further information on other alloys and methods of applying and controlling heat treatment activities.