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HEAT TREATMENT OF STEEL WELDMENTS

INTRODUCTION:

Heat treatment of metals and alloys has a pronounced effect on their properties and service behavior. Though in general, heat treatment of metals and alloys involves heating to a specific temperature and cooling, depending on the purpose and alloy type, the heating rate, cooling rate, temperature and time of holding, soaking varies widely. Different alloys show different responses to different heat treatments. So selecting the correct type of heat treatment for a specific alloy to achieve the desired properties is a formidable task. This becomes more interesting and intriguing in weldments since it comprises of the base metal, weld metal and the heat affected zone which many times respond differently to the same heat treatment. This is because the base material is a rolled, heat treated structure, the weld metal is a cast structure and the HAZ is a thermally affected, altered structure. The problems can be even more complicated if the materials are dissimilar. Extensive research conducted on several base materials, weldments have resulted in the establishment of many specifications, codes which specify the exact post weld heat treatment (PWHT) that has to be used mandatorily. Though this lessens the problem to a large extent, many times the actual job requirements tend to vary and a good knowledge on this subject can be helpful for overcoming the day to day problems on the shop floor. In this paper, an attempt has been made to give the details on the various aspects related to PWHT of weldments.

WHY HEAT TREATMENT OF WELDMENTS?

Welding, on completion, due to the non-uniform heating and fast cooling leaves lot of residual stresses, which are, usually tensile in nature in the weldments. This affects the service behavior of the welded joints and can lead to premature failure, cracking etc. These stresses have to be removed and that is the primary reason, most of the times, for a PWHT of the weldments. Though there are several heat treatments like annealing, normalizing, quenching and tempering, they are not very commonly performed on weldments. The most common type of weldments is the stress relieving heat treatment to relieve the residual stresses.

THE STRESS RELIEF HEAT TREATMENT (SR):

This heat treatment is done below the transformation temperature to relieve the residual stresses (Table 1). In this heat treatment the material is slowly heated to a specified temperature, held there for a specified time and then slowly cooled to room temperature. This process helps in relieving the residual stresses in the following way.

The maximum amount of stress that can remain in the material is its yield strength. As the material is heated, its yield strength starts decreasing and at temperatures around 6000C (for carbon steels), the yield strength almost reduces to zero which in turn means that it cannot hold any more stresses. So the residual stresses reduce to almost nil and when the material is slowly cooled it is without any residual stresses.

Since this is performed at temperatures below the transformation temperatures, no major structural changes take place. But the mechanical properties like UTS, YS, %El, CVN Impact, Hardness do vary. The corrosion properties also vary after this heat treatment. Depending on the material, the time temperature, cooling and heating rates vary. The following paragraphs will give more details on this.

MATERIAL WISE POST WELD HEAT TREATMENTS:

Usually the PWHT is specified by the codes. For base materials, the popular code ASME Sec VIII Div 1 (UCS 56, 56.1 etc) specifies the details as per material group (P-number). For the weld metals, ASME Sec II Part C (SFA 5.1, 5.5 etc) specifies the PWHT. Table 1 indicates the various details of these PWHTs. It can be observed that the temperatures specified in both these codes are similar though variations do exist. The normal holding time at these temperatures is one hour per inch of the section thickness and one hour minimum. It can also vary with thickness as per the codes. Apart from ASME, many other codes specify the mandatory details for PWHT, which are more or less similar to these. Depending on the requirement, the use of specific code should be made. These also specify the heating, cooling rates.

EFFECTS OF PWHT:

As indicated earlier, though there are no major structural changes during SR, the properties do vary and its nature, extent depends on the material, weld metal. Though it is very difficult to predict the changes, it is possible to give an idea of the general trends in various materials. Table 2 indicates these trends.

SPECIAL PWHTs:

Ageing for hydrogen removal is usually done to ensure that the diffusible hydrogen gets enough time to get out of the weld metal. This specially required for weld metals from rutile consumables and also for weld metals used in high strength steels. Ageing is usually done at around 2500C for long periods like 16hrs and normally done immediately after welding similar to post heating.

While the normal soaking time is one hour per inch of section thickness, prolonged soaking times may have to be used depending on the job requirements; e.g. in a single job thicknesses may be varying widely and if the soaking is done for the thicker section it may prove to be a prolonged one for the thinner section.

Use of multiple SR may be required in some cases; e.g. a job may be stress relieved in parts and then once again stress relieved as whole equipment; a repair done also may call for repetitive SRs.

Combination of heat treatments is also a possibility in some cases; e.g. a dished end made with a long seam will first undergo a normalizing heat treatment followed by a SR. In welding of steel castings also combination of heat treatments are usually encountered.

Apart from the above there are many specific heat treatments done to ascertain the weldments quality. A treatment called step cooling heat treatment is done to determine the susceptibility of the material, welded joint to temper embrittlement.
Table 3 gives details of these heat treatments and the weld metals on which they are used.

HEAT TREATMENT OF WELDED CASTINGS:

Steel castings are also welded to upgrade them and the amount of weld metal (and in turn the amount of residual stresses) depends on the extent, size of the defects. A large casting with large defects requires lot of weld metal deposition and it produces lot of residual stresses. Usually the welding of steel castings is governed by the ASTM specification A 488. While stress relieving is usually recommended in many cases by the casting specifications, if the dimensions of the repair exceed certain limits specified, then, the welded casting has to undergo the entire heat treatment cycle to which the original casting will be subjected to. This is a very severe demand on the weld metal and weldments since the weld metal is independently not subjected such heat treatments. The design, selection of the weld metal also requires special considerations in such cases.

ASPECTS TO BE TAKEN CARE OF DURING PWHT:

Oil, Gas, Induction, Electrical etc methods can be used for heating the material but for some materials like stainless steels, carbon pick up may be a severe problem with oil, gas heating. The component should be uniformly heated all around usually, except in specific cases where only local heat treatment is done. Temperature measurement should be done at different places (this is usually specified) to ensure uniformity of temperature all around. A temperature recorder is necessary to plot the temperature vs. time and this is usually inspected and signed by an inspector and forms a permanent record for the equipment.

Local heat treatment when permitted and followed in specific cases, the heat should be applied to the specified width and for the specified time.

Normally a production coupon which was welded along with the main component is also subjected to this PWHT and is tested destructively after the PWHT to ensure conformance to properties.

It is necessary to give adequate support to components, vessels during the heat treatment process inside the furnace as the materials have very low yield strength at those high temperatures because of which they can distort due to their own weight itself.

AVOIDING PWHT:

In some cases, especially in repair and maintenance welding, it is difficult and not practicable to do a PWHT. In such cases, a judicious choice of weld metal can solve the problem to a large extent. These weld metals are usually ductile and the residual stresses generated are relatively low when they are used. Table 4 gives details of weld metals that can be used in some cases to avoid the PWHT.

CONCLUSION:

Post weld heat treatment is an important step in the fabrication activity and most of the times are governed by the fabrication codes and specifications. Since properties can get altered with PWHT, it is necessary to perform this operation with due understanding and with care so that the ultimate performance of the weldments is not affected.

Table 1: MATERIAL WISE PWHT

Base meal P no	Sub group	Min PWHT temp 0C	Alloy type	Electrode classification	PWHT at 0C plus minus 140C
1	1,2,3	650	C-Mn	E7018	620
3	1,2,3	595	C-Mo	E7018-A1	620
4	1,2	650	Cr-Mo	E8018B2	690
5A	1	675	2Cr-1Mo	E9018B3	690
5B	1	675	5Cr-1Mo	E8018B6	740
5B	2	705	9Cr-1Mo	E9018B9	740
5C	1	675	2Cr-Mo-V-	E9018B3	690
9A	1	595	2.5Ni	E8018C1	605
9B	1	595	3.5Ni	E8018C2	605

TABLE 2: EFFECT OF PWHT

MATERIAL	PWHT TYPE	EFFECT
C-Mn steel	SR	Stresses get relieved; UTS, YS get reduced; %Elongation improves; toughness may show improvement; hardness reduces;
	Multiple SR	Strength can drastically reduce; impacts will suffer; grain coarsening is a possibility
	Normalizing +SR	Strength will reduce;
	Prolonged SR	Strength will reduce; impacts likely to suffer;
Cr-Mo steels	SR	Stresses get relieved; hardness comes down; Strength will show reduction
	Prolonged SR	May get embrittled;
	Multiple SR	May get embrittled
Ni steels	SR	Reduction in strength; may deteriorate in impact properties;
	Prolonged SR, Multiple SR	Impacts will suffer
Stainless steels	SR	May get embrittled; corrosion properties may suffer; normally not recommended

TABLE 3: SPECIAL PWHTs

PWHT	Heat treatment Cycle	Usual materials to which it is applied
Ageing	2500C for 16hrs.	For removal of diffusible hydrogen; for C-Mn steels, high strength steels
Prolonged SR	For 4, 8, 12 hrs.	For C-Mn steels, Cr-Mo steels
Multiple SRs	Double, Triple cycles	For C-Mn steels, Cr-Mo steels
Combinations	Usually a normalizing + SR	For C-Mn steels
	5400C for 40 hrs followed by 6500C for 8 hrs three times	For low alloy steels
	SR +Q&T and tempering	Used on castings where full heat treatment is to be done after welding; for low alloy steels;
Step cooling	5930C-1hr; 5380C-15hrs; 5240C-24hrs; 4960C-60hrs; 4680C-100hrs.	For Cr-Mo alloys

Table 4: AVOIDING PWHT

WELD METAL	APPLICATION
25Cr-12Ni	For welding martensitic stainless steels
29Cr-10Ni	For welding alloy steels, C-Mn steels
25Ni-15Cr-5Mo	For welding Cr-Mo alloys
Ni-15Cr-5Mn-6Fe-1.3Nb	For welding many dissimilar combinations

For further details, please visit us www.adorwelding.com or write to us cmo@adorians.com

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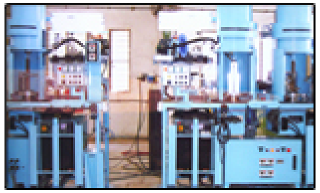
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