البحث رقم (٦)

Heat treatment and post weld for steel and its alloys

المعالجة الحرارية وتحسين مواصفات الحديد الصلب وسبائكها ــ بعد عملية اللحام

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الملخص العربي:

المعالجة الحرارية بعد عمليات اللحام غالبا ما تستخدم لتحسين مواصفات الأجزاء التي تعرضت لعمليات اللحام، المعالجة الحرارية بعد عمليات اللحام تشمل معالجات عديدة حيث أنها تستخدم لتقليل الإجهادات المتبقية بعد عمليات اللحام وأيضا كوسيلة للتحكم في صلابة المواد وزيادة قوة المواد، إذا ما تمت المعالجة الحرارية بعد عمليات اللحام بطريقة صحيحة يمكن ان ينتج عنه فشل في عمليات اللحام ويزيد من احتمالية حدوث كسر او تلف وانهيار في المادة الملحومة.

Abstract

Post weld heat treatment (PWHT) defined as any heat treatment after welding, is often used to improve the properties of a weldment. In concept, PWHT can encompass many different potential treatments. PWHT can be used to reduce residual stresses, as a method of hardness control, or even to enhance material strength. If PWHT is performed incorrectly, or neglected altogether, residual stresses can combine with load stresses to exceed a material's design limitations. This can lead to weld failures, higher cracking potential, and increased susceptibility to brittle fracture.

Heat treatment

During heat treatment. A material or work piece is subjected to temperature changes in order to create appropriate processing and utilization characteristics via structural changes. A distinction is made between different heat-treatment methods:

- Stress- relief annealing
- Soft annealing
- Normalizing
- Coarse grain annealing
- Hardening
- Quenching and tempering

Stress Relief Annealing

Stress- relief annealing serves to reduce stresses caused by uneven cooling or by welding, heat treatment are relieved by means of creeping, in fact up to the yield strength of the material, which is reduced due to the temperature. Complete stress relief (i.e. stress – free annealing) is not possible because the yield strength cannot be lowered to zero.

Soft annealing

Without altering the iron carbon ratio, soft annealing should make steel suitable for subsequent shaping. In an unalloyed structural steel, perlite is the harder structural proportion, which is to be converted to a softer form by means of soft annealing. Therefore, the heat treatment must be carried out in the region of the A_1 line. For this purpose:

A The pearlite can be dissolved by annealing it for 2-3 h at temperatures of 10 -20 C below A1. The pearlite consisting of cementite and ferrite lamellae changes its structure to such an extent that the cementite lamellae are formed into spherical structures. Indeed every substance endeavors to take on a spherical shape since this has the smallest surface;

B the cementite can be formed by means of cyclic annealing (20 C) around A1. This case, the cementite lamellae are strained and clenched constantly unit they begin to tear. These shorter frag- mints are formed more easily and rapidly. Therefore, this type of soft annealing proceeds more quickly.

Spherical cementite proportions can shift better in the ferrite matrix, thus improving the plastic ductility.

Normalizing

The objective of normalizing is to achieve a fine-grained structure, which, with the same strength, has higher toughness than the coarser grains. Locally, coarser grains lead to greater stresses at the gain boundaries and restrict the ductility. Finer grains can distribute stresses in the structure by deforming many smaller regions. Fine- grained steel therefore has greater ductility.

In steel, coarse grains may occur in the ferrite and in the pearlite.

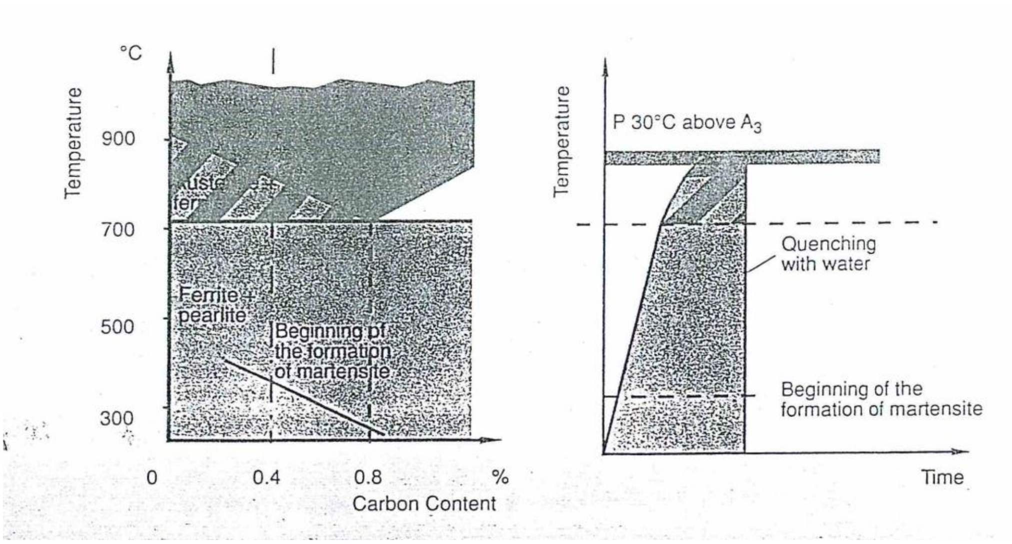
In order to influence the grain size, the heating process must be carried out higher than the A3 line so that the entire structure can form again during the repeated cooling .

For normalizing، the A3 line must be exceeded by approx... 30 C. it is possible to achieve a more fine – grained austenite structure solely be means of rapid heating. Indeed, if the heating rate is higher than the austenite-nucleation rate the majority of these nuclei only occur at temperatures which are just below the A3 line (in the case of slow heating, nuclei which develop into an overall structure arise gradually beginning from A1; this process is suppressed by means of rapid heating) . because of the large number of nuclei, the many crystals forming do not have any space to develop into larger grains. Since they hinder each other, this results in fine- grained austenite. If the cooling process is also quicker than the rate at which ferrite grains can grow, the grains in the structure become even smaller. After the cooling process, which is genre-ally, carried out in air in the case of steels, there is then a doubly refined grain.

Hardening

By means of hardening. The steel should be given high resistance to wear and to compressive stresses. In many cases, the hardening effect occurs unintentionally during welding. Temperatures approx. 30 C above A3 are assumed for the hardening process. Austenite is thus present. If the cooling rate is increased (e.g. by means of cooling in oil), the step-by-step mechanism of gradual temperature-dependent ferrite precipitation is suppressed. this results exclusively in pearlite with an average carbon content corresponding to that of the original overall structure (not 0.8 % as otherwise customary) since the alternate formation of ferrite and cementite lamellae must take place in an accelerated process. The more frequent alternation leads to more and finer lamellae. Because cementite (the harder proportion of the pearlite) occurs more often, the steel is harder although the average proportion of the carbon content in the pearlite is lower than 0.8% with regard to a normally formed pearlite, a value between those for the hardness of the cementite and ferrite lamellae is determined when the tip of a hardness testing device is pressed in. in the case of pearlite which forms more rapidly and therefore has fine streaks as well, the tip of the hardness testing device basically rests on the cementite lamellae and therefore indicates higher hardness values.

This process which can be achieved just by cooling the steel in oil can lead to direct quenching by means of water cooling. In this case, the temperature decreases more quickly than ferrite and pearlite can form from the austenite. Because the carbon is not given any time to shift into the lattice of the residual austenite, it remains locked in the a lattice which wants to from. The lattice and structural shape produced is marten site which is shown as a whisker in the micrograph. Because the hardness depends on the number of locked-in carbon atoms, marten site is already formed at a lower critical cooling rate as the carbon content increases. The critical cooling rate designates the cooling rate at which marten site forms for the first time. A high carbon content and / or a high cooling rate result in a large number of carbon atoms locked in the lattice and lead to an increase in hardness. By means of prior normalizing, a finer marten site structure with smaller and shorter whiskers is produced instead of a coarser marten site structure, thus once again resulting in a slight improvement in the mechanical laudability of the steel. It makes sense to harden stills with a carbon content as from 0.4%



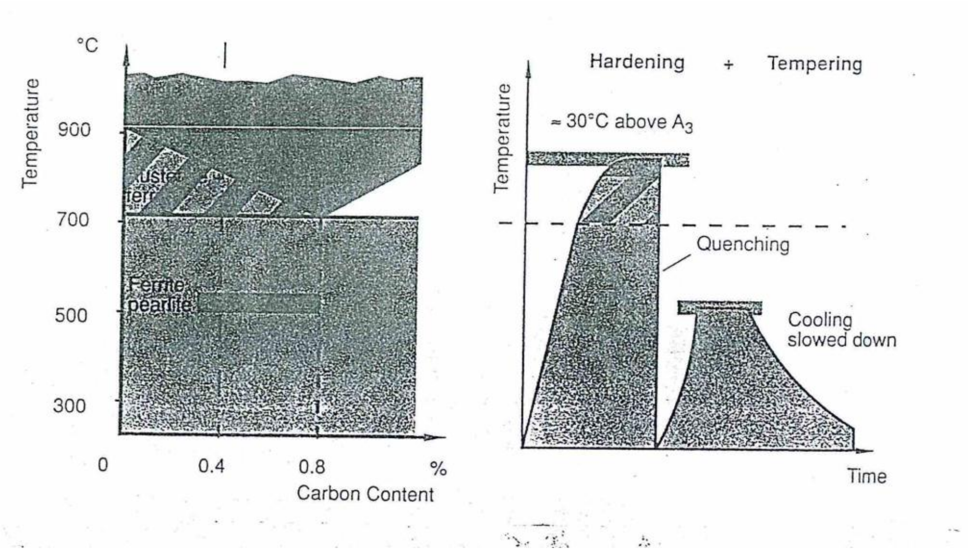
Quenching and tempering

Hardening and subsequent tempering is designated with the term quenching and tempering. By means of tempering below A1 after the hardening process, it is possible to increase the ductility of the structure to the same extent as its hardness decreases. Bothe characteristics are directly coupled with each other and are directly dependent on the temperature.

In comparison with steel which is only hardened. Quenched-and-tempered steel has one fundamental advantage: quenching and tempering produce a steel with high hardness. Tensile strength and yield strength as well as good toughness. One prerequisite for quenching and tempering is hardening as shown on the figure. Normalizing can also be carried out beforehand. After the hardening process. The steel is reheated to temperatures below A1 because the hardness structure would otherwise disintegrate totally or partially once again due to the formation of austenite grains. This process is called tempering. In the case of welding in several passes, the passes welded previously are partially tempered by the welding of the next pass:

The lower the tempering temperatures is, the more the hardness and thus the reduced toughness are retained. The tempering gives rise to the temperature – induced enlargement of the marten site lattice. Some of the carbon atoms which can move more easily as a result of this diffuse out of the marten site lattice, form iron carbides and are added on to the previous marten site. An acicular structure is formed which has a similar shape to that of the marten site whiskers but is softer.

Quenching and tempering

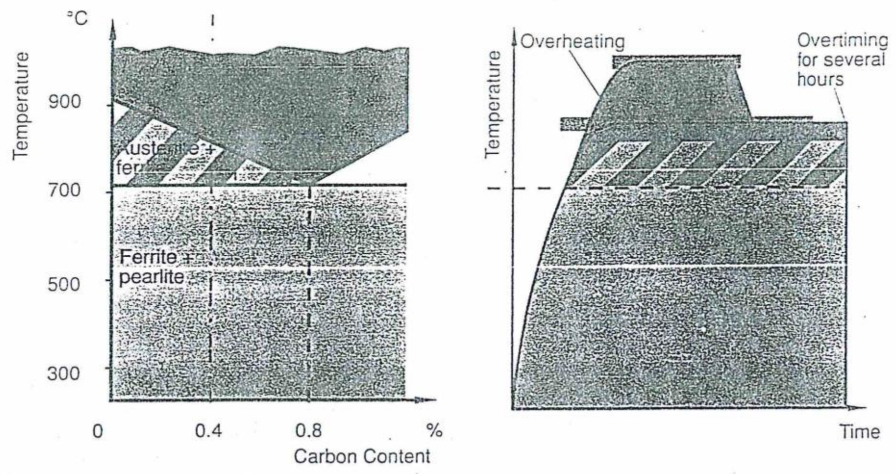


Coarse – Grain Annealing

In contrast with normalizing, the objective of coarse-grain annealing is to produce coarse grains. During welding , the undesirable effect occurs inevitably as overheating and may lead to extreme embrittlement. If the heat input is unnecessarily high, this overheated zone may be very large.

For coarse – grain annealing in which several grains of the structure grow together in order to form on common large grain without any grain-boundary differences, the structure must firstly be transformed into austenite. High-melting aluminum and silicon oxides (impurities) are situated at the grain boundaries. These are transported away from the grain boundaries or are formed into spherical structures. Where pure lattices are located opposite each other May harmonies their direction one common grain may thus form large number of grains coarse grains may to convert into fine grains by means of normalizing, i.e. by crossing the A3 line in the upward direction once again.

Coarse grain annealing

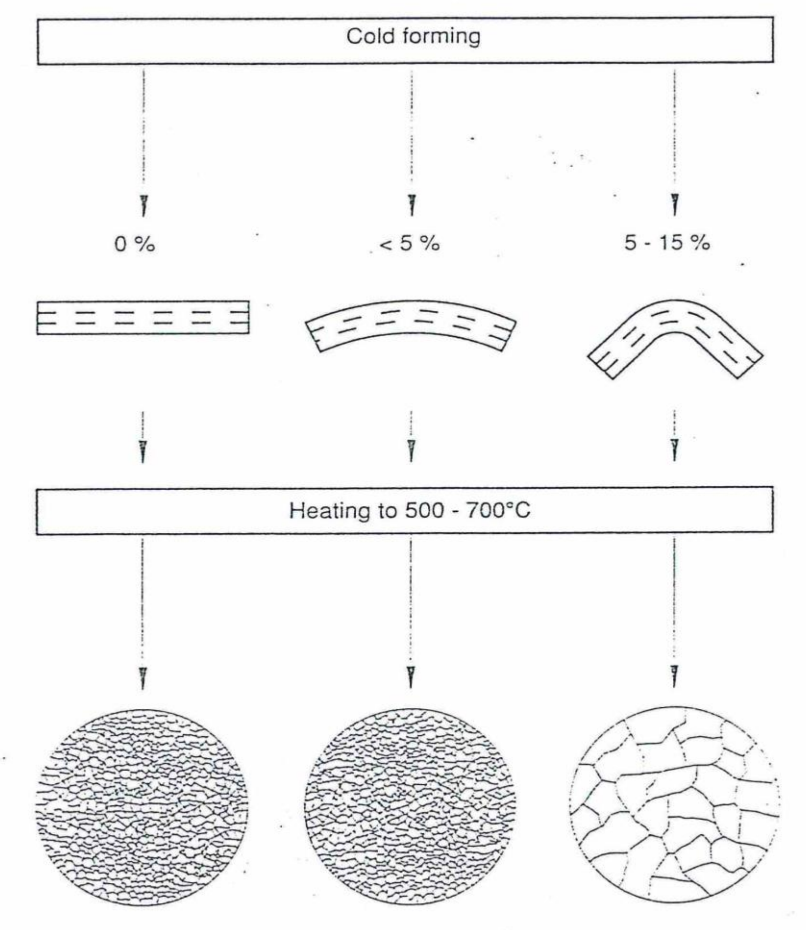


Recrystallization Annealing

The heating does not exceed 723 C; usually. This does not result in any changes in the structure or in the material properties. Two exceptions are important for practice:

1- At temperatures between 500 C and 700 C , a cold-formed structure undergoes a change in the grain size. This process is called recrystallization. Cold forming of approx.. 5-15 % (critical degree of deformation) results in a coarse-grained structure exhibiting low toughness. Attention must be paid to this when cold –formed steels are welded. The welding heat may cause the cold-formed regions to become so coarse-grained that there is a risk of brittle fracture. The conditions for the welding of cold-formed steels are therefore stipulated in standards and technical guidelines.

2- At temperatures of 200 – 400 C(blue temper heat) , “artificial ageing” may occur. The prerequisites for this are a cold-formed structure and a minimum concentration of nitrogen in the steel. The ageing leads to an extreme drop in toughness.



Introduction:

During the fabrication process, welding is the most commonly used method of joining items together. The welding process generally involves melting and subsequent cooling, and the result of this thermal cycle is distortion if the welded item is free to move, or residual stress if the item is securely held. There comes a point when the amount of residual stress can create potential problems, either immediately or during the life ot the welded structure , and it needs to be reduced or removed. Post weld heat treatment is the most widely used form of stress relieving on completion of fabrication of welded structures. The principle is that as the temperatures is raised, the yield stress and the elastic modulus of the material fall.

Scope

Post weld heat treatment refers to the process of reheating a weld to below the lower transformation temperature at a controlled rate, holding for a specific time and cooling at a controlled rate, No consideration has been given to normalizing of welds in carbon-manganese and low alloy steels, to solution annealing of stainless steels or to any precipitation hardening treatments to other alloy materials.

Why the need for post weld heat treatment ?

Residual stress

The development of residual stresses approaching or even exceeding or even exceeding the yield stress is possible when welding thick sections.

PWHT conditions

Each specimen for mechanical properties evaluation was subjected to PWHTs. For weld metal A, the PWHTs were conducted fat five temperatures : i.e 670 , 730 , 760 , 790 , and 820 C. for weld metal B, PWHTs were conducted at four temperatures; i.e 720, 760 , 800 and 850 C. the holding time for each PWHT was 4 hrs. the lower control limit for the PWHT temperature was 300C, while the heating rate and above the lower control limit temperature were 55C / h or lower.

Mechanical properties evaluation of weld metal

The mechanical properties evaluated were tensile strength at room temperature, chirpy impact absorbed energy at 20 C and the creep rupture time at 600 C (applied stress : 108MPa and 147MPa) .

Tempering effect

Post weld heat treatment will generally result in a modification of the microstructure of both the weld metal and heat affected zone. With the exception of the 9 Cr1 Mo and 12 Cr1 MoV materials, the microstructure of all other materials should contain a mixture of ferrite and iron or alloy carbide. The effect of short term (1 to 2 hours) post weld heat treatment on the carbide is generally beneficial, whereas longer times result in a reduction in toughness due to spheroid sing effects. The normal microstructure for the parent, weld and HAZ for the 9 Cr1 Mo and 12 Cr1 MoV materials is marten site, and post weld heat treatment is essential in these materials to temper the martensite phase.

Effect on creep properties

For creep resisting material, post weld heat treatment is required in order to fully develop the creep strength. This is especially true for thicker components such as headers. There has been a tendency in recent years to allow waiving of the post weld heat treatment stage for thinner materials used typically for superheated and reheated coils in the power generation industry, but a variety of conditions have to be met

Benefits:

1- Softening the heat affected zone and Tus improving toughness (although not weld mental toughness)
2- Improving ductility.
3- Reducing the effects of cold work.
4- Improving the resistance to stress corrosion cracking.
5- Improving the diffusion of hydrogen out of weld metal.
6- Improving dimensional stability during machining.

When to post weld heat treat:

The material (in terms of alloy content) and the thickness (in relation to the quench effect) control the microstructure that will be formed. Large section thicknesses in alloy steels can result in martensitic, prelatic or abiotic structures depending on the cooling rate, and this is usually controlled by the use of preheat . in addition, the thicker the material that is welded the greater the amount of residual stress that will be developed on cooling.

For carbon- manganese steels, the thickness at which post welt heat treatment become mandatory is consistent in the 32 – 38 mm range for most of the codes in use in Australia.

With alloy steels , the thickness at which post weld heat treatment becomes mandatory is much less. Typically, the range is 13-20mm, and even below 13 mm, a series of strict conditions have to be met before post weld heat treatment can be waived. That with alloy steels, the removal of residual stress is not the only consideration for the application of post weld heat treatment

Post welt heat treatment of structural steels is almost unheard of . even in the offshore industry , the Nodes and K-joints on the Jacks are no longer post weld heat treated.

Fixed furnace:

A fixed furnace usually consists of a rectangular box made from heat resistant materials in which are embedded electric resistance elements. Doors open at each end and a travelling bogie allows for loading and unloading of the charge. Furnaces such as these are often capable of heating to 1200 C and can normalize and anneal as well as stress relieve. Some furnaces are gas fired with tow or even four nozzles at each end.

Fixed furnaces tend to be large and expensive to operate. They often have fixes thermocouples that measure the furnace atmosphere temperature and not the temperature of the article being heat treated .

Furnaces such as these must be equipped with correctly calibrated temperature controllers/recorders with at least 12 recording points.

Care must be taken when cooling after post weld heat treatment . most manufacturing codes specify a controlled rate of cooling until a certain temperature is reached (typically 300-400 C depending on the thickness) , so it is normal to control cool in the furnace before opening the doors.

Heating/ cooling rates v

These are specified in most of the construction standards, and are reasonably similar. For example, as 4458 for carbon manganese steal vessels limits heating and cooling rates to 200 C / hour for thicknesses up to 25 mm, and 5000 C hour divided by the thickness. For vessels over 25 mm. there is also a minimum limit of 50 C hour for very thick vessels. However, for ½ Cr ½ Mo ¼ V and 2 ¼ Cr1 Mo alloys, the heating rate is limited to half that of carbon manganese steels. For comparison , EN 13445 allows 220 C/hour up to 25 mm thick, 5500/thickness for 25 to 100 mm and 55 C/hour above 100mm thick. There are no restrictions on the alloy steels in EN 13445 .

Omission of post weld heat treatment:

There are number of situations where pressure equipment requires work to be done due to the service environment, and such work often involves welding typical situations include:

- Repairs due to mechanical damage
- Repairs due to a corrosion mechanism, including cracking.
- Repairs due to creep damage.
- Repairs to service-propagated defects.
- Repairs to original manufacturing defects.
- Modifications to take advantage of the economic situation.
- Modifications due to changes in raw material feed.

EXPEREMENTS FOR HEAT TREAMENTS THE WELDING PARTS:

NOTES:

- Welding parts with hard heated should be slowly cooled to avoid cracks and bending as a result ciaos stretching for all parts.
- High speed of heating causes burns the edge of parts and oxidizing.
- To get perfect structure grains that we needs we should rise the welding parts vertical at the surface of cooling liquid with fast action.
- Cooling liquids should be clean and without slags materials.
- Heating time should be chick depending on heat treatment proses.
- Heat treatment for work piece take (20 * 20) mm takes (15) min at least.
- for hardening proses the metal should be rise the heating (30 – 50) degree above

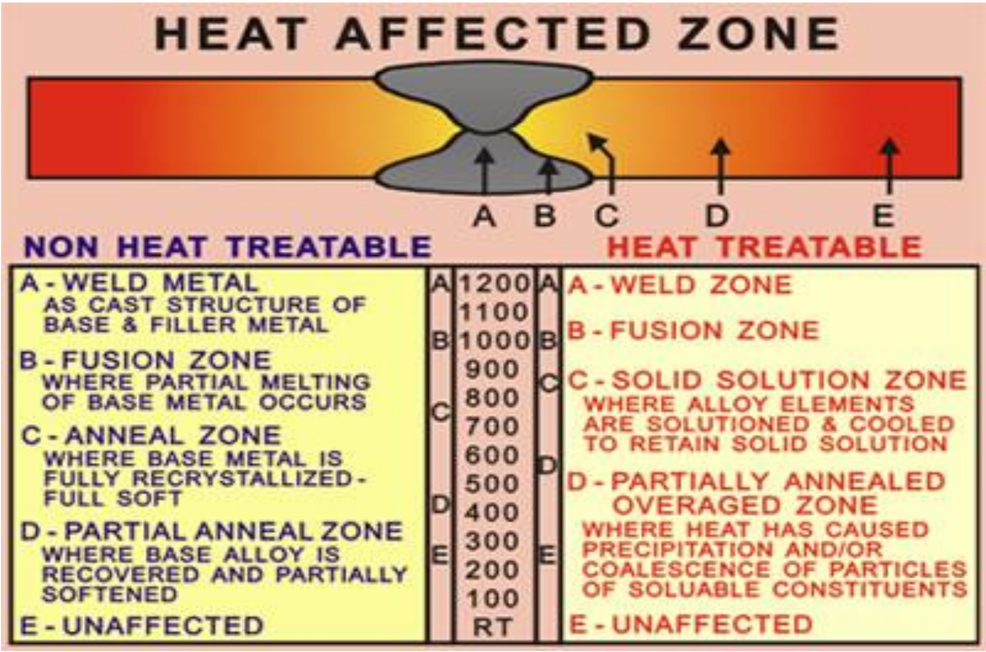
Line (KSP) CARBON STEEL DIAGRAM to get fine grains structure.

- With fracture test for carbon steel at row materials the grains is large.

EXPEREMENTS FOR HEAT TREAMENTS THE WELDING PARTS WITH HEAT AFFECTED ZONE:

- NON-HEAT TREATABLE
- HEAT TREATABLE

IT WILL BE SHOWN IN FIGGER



EXPEREMENT (1):

TO DETERMINE THE RELATIONSHIP BETWEEN THE TEMPERATURE OF HEAT TRETMENTS AND THE GRAINS SIZE.

TYPE OF WORK PIECE: C60

EXPEREMENT STEPS:

- Prepare 5 piece with (40) mm diameter 14 mm.
- Mature with hardening (67, 5) HRC with (20 c).
- First work piece with (200 c) and hardening (63) HRC.
- Second work piece with (260 c) and hardening (57, 5) HRC.
- Third work piece with (300 c) and hardening (56, 5) HRC.
- Fourth work piece with (360 c) and hardening (53, 5) HRC.
- **Fifth work piece with welded parts (360 c) and hardening (53, 5) HRC.**
- Work pieces should be stay in furnace for (200- min) thin leave to cooldown slowly.
- Record the results

RESULT:

- first work piece (fine grains structure)
- second work piece (fine grains structure)
- third work piece (big and rough grains structure)
- fourth work piece (Medium-grains structure)

NOTE:

The carbon steel welded parts with hardening structure in high

Temperature heat treatment

Will be get more ductility with no healing affected zone and fine grains structure.

RESULT:

WITH ANNELING THERE IS LESS HARDINING, MORE DUCTILITY, FINE GRAINS

GOOD PROPERETIES.

EXPEREMENT (2):

TO IMPROVE THE RELATIONSHIP BETWEEN THE HARDINING AND THE SPECIFIC TIME OF COOLING

TYPE OF MATERIAL: CARBON STEEL (C60)

SIZE OF WORK PIECE: Prepare 5 piece with (40) mm diameter 14 mm.

EXPEREMENT STEPS:

- rising temperature of furnace to (840 c)
- Heating First work piece for (3 min) and cooling down in water.
- Heating second work piece for (8 min) and cooling down in water.
- . Heating third work piece for (11 min) and cooling down in water.
- Heating fourth work piece for (15 min) and cooling down in water.

- Heating fourth work piece for (18 min) and cooling down in water.
- Every work piece with handing number (37/53, 6/65/65/65) HRC.
- Make fracture test for all pieces
- Chick the grains for all piece
- Record the results.

NOTE:

THE ROTE MATERIAL WITH HARDNING NUMBER (30) HRC

RESULTS:

- The hardening rise until getting at (11min) then stay hardening number constant whatever if rise the temperature.
- The grain structure of the material will more fine until we get at (15 min) and it will be bigger grains as we rise the temperature.
- We will reach the note that is the time for heating (1 mm) is (1-0, 75) min.

❖ Technical advantages

Of the effects that post weld heat treatment has on a weld, residual stress will obviously remain if post weld heat treatment is waive, and for creep resisting materials, the full creep strength will not be developed. However, there are welding techniques that can simulate the tempering effect of post weld heat treatment, and there are some claims that mechanical properties in the HAZ can be improved compared with conventional post weld heat treatment. The particular property that is influenced more than any other when welding with these alternative techniques is heat affected zone toughness. Most of the so-called temper bead techniques are primarily designed to give adequate toughness in both the weld and the heat affected zone and to produce a satisfactory hardness profile. Whether the room temperature, and sometimes sub-zero impact. Properties are the most important consideration with alloy steels operating in the creep range is indeed questionable

After having said that, there is no doubt that for materials susceptible to reheat cracking, the absence of post weld heat treatment and the absence of the coarse – grained heat affected zone are definite advantages. Care needs to be exercised however, and suffice it to say that the justification for waving post weld heat treatment on technical grounds should not be confused with economics.

Qualification of welding procedures :

The application of post weld heat treatment is and essential variable . this means that the application of post weld heat treatment to a procedure or the removal of it from a procedure requires re-qualification. This is because pose weld heat treatment affects the mechanical properties of the weld, and this is the whole purpose of procedure testing .

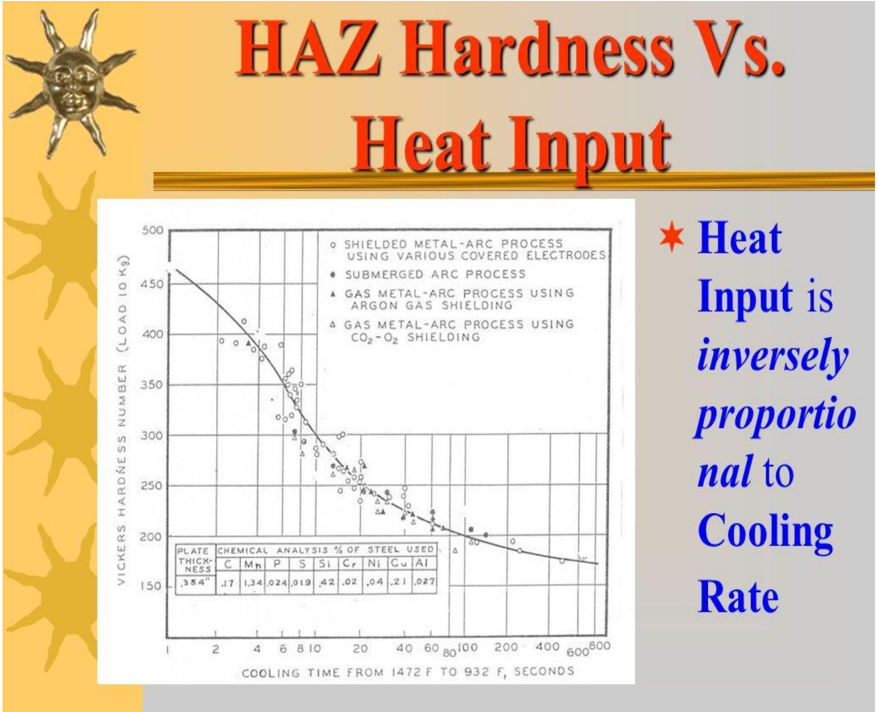
There are even more restrictions if heat treatment is above the lower transformation temperature, but this guidance note has been limited to the stress relieving aspect of post weld heat treatment.

Caution must also be exercised when working with the ASME code . the system of supplementary essential variables can be confusing, but basically, these are invoked whenever notch toughness requirements are specified . in the case of post weld heat treatment, there is and additional essential variable that specifies that the procedure qualification test shall be subjected to post weld heat treatment essentially equivalent to that to be encountered in production, including at least 80% of the aggregate time at temperature. Taking a practical

Example of this, a 50mm thick

procedure qualification test plate requiring impact testing and representing a 50 mm shell plate would normally only have been held at temperature for 2 hours (ie. 1 hour / 25 mm). In practice , that same vessel may have different shell thicknesses or even a tube plate, and the 50 mm shell may have reached the holding temperature long before the rest of the vessel . quite often, the shell is at temperature for 5 or 6 hours, so the procedure qualification test needed to be at temperature for 6 hours x 80 % ie 4 hours 50 minutes and not the 2 hours it received.

Under these conditions, re-qualification would be necessary.



CONCLUSION:

- Using heat treatments softening the heat affected zone and it will be improve toughness for the welding parts.
- It will be reduce the effect of cold work.
- Improve the ductility in welding joints.
- It will be improve the resistance to stress cracking.
- Improve dimensional stability during machining.
- Improving the diffusion of hydrogen out of weld joints.

References:

1- Heat treatment of steel – welding processes – slv mannhiem GMPH DR-ING.LLEISEIN INSTITUT (page 1-8)

2- Effects of post weld heat treatment (PWHT) temperature on mechanical properties of weld metals for steel Genichi TANIGUCHI, Ken YAMASHITA-(page 9).

3- Tempering heat treatment effects on steel welds A.V. adedayo1, S.A. ibitoye1 and O.O Oluwole (page 9-10)

4- Key concepts in welding engineering by R.Scott Funderburk (page-11)

5- EXPEREMENTS FOR HEAT TREAMENTS THE WELDING PARTS (by boblosher – as lab experiment – 12-14)

6- Post-weld heat treatment – case studies

Khaleel Ahmed and J. Krishnan centre for design and manufacture bhabha Atomic Research Centre (page – 15)

7- Post weld heat treatment of welded structures (welding technology institute of Australia) (page- 16)

8- Conclusion (page- 17)

المراجع:

١- المعالجة الحرارية للصلب الكربوني – تقنيات اللحام – المعهد الألماني – منهايم تبعا للمناهج المعتمدة للتدريب – لمدربي الهيئة العامة للتعليم التطبيقي والتدريب.

٢- تأثير المعالجة الحرارية بتحسين الخواص الميكانيكية للأجزاء الملحومة.

٣- تأثير التبريد البطيء بعد عمليات المعالجة الحرارية في تحسين الخواص الميكانيكية.

٤- اساسيات لهندسة تقنية اللحام والمعالجة الحرارية للقطع الميكانيكية.

٥- تجارب مخبرية بورش اللحام وبعض النتائج التي تأكد فعالية المعالجات الحرارية لتحسين الخواص الميكانيكية بعد عمليات اللحام.

٦- التركيب الجزيئي ومدى تأثير المعالجات الحرارية في إعادة تنظيم التركيب الجزئي للقطع الملحومة.