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GUIDANCE NOTE 6

POST WELD HEAT TREATMENT OF WELDED STRUCTURES

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 of 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 temperature is raised, the yield stress and the elastic modulus of the material fall. A point is reached when the yield stress no longer supports the residual stresses and some localised plastic deformation occurs.

The objective of this Guidance Note is to describe the various post weld heat treatment techniques, when it has to be used and the circumstances where it can legitimately be avoided. The Note is also intended to assist the Fabrication Industry in providing information on where to look for guidance on post weld heat treatment heating rates, cooling rates, holding temperatures, holding times, thermocouple placement, thermocouple attachment, and qualification of welding procedures. It is intended for use by Welding Supervisors, Welding Inspectors, fabrication personnel and Engineers involved in both the fabrication industry and typical Owner/Operator industries.

SCOPE

Post weld heat treatment in the context described here 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 normalising 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. Therefore, almost by exclusion, the materials involved will be C-Manganese steels, C-Mo, 1¼Cr½Mo, 2¼Cr1Mo, 5Cr1Mo, 9Cr1Mo and 12Cr1MoV steels.

WHY THE NEED FOR POST WELD HEAT TREATMENT?

Residual Stress

The development of residual stresses approaching or even exceeding the yield stress is possible when welding thick sections. For certain industry sectors, eg. Petrochemical, Chemical, Oil and Gas, etc. the existence of residual stress of this magnitude is completely unacceptable. With pressure equipment operating at 200^0 C and below a variety of stress corrosion cracking mechanisms under the general term "environmental cracking" become prevalent. There is also the problem of fatigue to be considered and the effect that residual tensile stresses have in that regard.

Other industries such as Power Generation have different considerations, and the stress developed due to thermal expansion of pipework can take on a far greater significance than residual stress due to welding. It is interesting to note that it can be shown (1) by the use of the Larson-Miller parameter that residual stresses in non-post weld heat treated welds are almost fully relaxed after approximately 20,000 hours at a service temperature of 540^0 C.

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 9Cr1Mo and 12Cr1MoV 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 spheroidising effects. The normal microstructure for the parent, weld and HAZ for the 9Cr1Mo and 12Cr1MoV materials is martensite, and post weld heat treatment is absolutely essential in these materials to temper the martensite phase.

Effect on Mechanical Properties

As a series of very general statements, the following are the consequences of post weld heat treatment compared with the as-welded condition:

- ✷ Yield strength is decreased slightly, the effect falling off fairly rapidly with time.
- ✷ The tensile strength is decreased.
- ✷ The ductility is increased.
- ✷ Hardness levels are reduced.
- ✷ Toughness is slightly reduced at short times but the effect can be significant over longer times.

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 superheater and reheater coils in the Power Generation industry, but a variety of conditions have to be met.

Other benefits

✷ Improving the diffusion of hydrogen out of weld metal

✷ Softening the heat affected zone and thus improving toughness (although not weld metal toughness)

✷ Improving dimensional stability during machining.

✷ Improving ductility.

✷ Improving the resistance to stress corrosion cracking.

✷ Reducing the effects of cold work.

WHEN TO POST WELD HEAT TREAT

Within pressure equipment standards, the requirement for post weld heat treatment is largely a function of the material and the thickness. 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, pearlitic or bainitic 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 typical carbon-manganese steels, the thickness at which post weld heat treatment becomes mandatory is consistent in the 32 – 38 mm range for most of the Codes in use in Australia. The reason for each standard choosing a specific thickness is not entirely clear, but little has changed over the past 30 years. What is interesting though is that experiments conducted in the mid-1970s showed that fully restrained butt welds in carbon-manganese steels could develop residual stresses in excess of the yield stress at a thickness of approximately 35 mm.

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

Post weld heat treatment of structural steels is almost unheard of. Even in the offshore industry, the Nodes and K-joints on the Jackets are no longer post weld heat treated. When that industry was in its infancy, post weld heat treatment was mandatory and was applied, but very little CTOD information was available then, and the materials in use suffered laminar tearing. That has all changed now, and very few joints require any attention today. Similarly, the massive machines in use in the mining industry are not subjected to post weld heat treatment, and it is not even addressed in the range of structural welding standards, AS 1554 parts 1 to 6. Therefore, the topic is essentially limited to the pressure equipment industry.

HOW TO PERFORM POST WELD HEAT TREATMENT

General

Most of the requirements for post weld heat treatment can be found in the fabrication Standard to which the vessel is constructed. In Australia, most fabrication standards now refer to AS 4458 for manufacture, and all details can be found there. The American Standards still tend to retain their own requirements, and ASME I, ASME VIII Division 1 and ASME VIII Division 2 are all different. Part 4 of the new EN 13445 deals with manufacture, and contains a lot of detail on post weld heat treatment.

Fixed Furnace

This method is traditional and well known to most people in the fabrication industry. 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 1200^0 C and can normalise and anneal as well as stress relieve. Some furnaces are gas fired, with two or even four nozzles at each end.
Fixed furnaces tend to be large and expensive to operate. They often have fixed thermocouples that measure the furnace atmosphere temperature and not the temperature of the article being heat treated. This is usually satisfactory up to around 300^0 C, but beyond, thermocouples physically attached to the article must take over both temperature control and temperature measurement. 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 – 400^0 C depending on the thickness), so it is normal to control cool in the furnace before opening the doors.

Temporary Furnace

These are custom-built around a vessel, rather than transport a vessel to a fixed

furnace. The idea is to minimise the air space between the vessel and furnace walls, and they allow for faster heating and cooling. The basic structure of the furnace should be creep resisting piping (if the pipes are to be continually re-used) with heat resistant materials attached to them. Heating can be through resistant heating mats placed on a concrete floor or via gas burners placed at each end.
In the case of gas burners, care must be taken to avoid direct flame impingement on the vessel.

Temperature control is again through a 12 point recorder/controller, but atmosphere thermocouples are not generally used. The same heating and cooling rate restrictions apply as with fixed furnaces.

Internal Firing

Vessels of suitable dimensions and arrangement of openings can be post weld heat treated by gas firing through nozzles or manways. Manways are large enough to accommodate the gas burners, but care needs to be exercised with the diameter and position of nozzles and expert opinion should be sought. Care must also be taken to place deflector plates inside the vessel and opposite the burner entry points to avoid direct flame impingement on the shell. It is not advisable to post weld heat treat vessels that contain internals in this manner.
The outside of the vessel must be completely encased in insulating material, and again, at least a 12 point temperature recorder is advisable.

Local Heating

Circumferential weld seams can be post weld heat treated by heating a band around the weld. Although not specifically stated, such heating is essentially limited to resistance or induction heating, mainly because of the controls required on heated band width, width of insulation and temperature measurement requirements. The use of gas ring burners and other methods should be carefully documented, proposed to the Client and accepted before being contemplated for use.
Typical restrictions on the width of the heated band in both AS 4458 and EN 13445 involve the use of a formula, ie. $5(Rt_s)^{½}$ where the weld is in the centre and:

R = inside radius of the shell, in mm
t_s = nominal shell thickness, in mm
This means that with a vessel of say 2 metre inside diameter and 50mm wall thickness, the minimum width of the heated band would be

$$5 \times (1000 \times 50)^{½} = 1118 \text{ mm}$$
or 560mm each side of the weld.

In addition to this, the width of the insulated band is recommended to be $10\,(Rt_s)^{½}$, which in the above example would be 2236mm. This is to ensure that the temperature gradient of the portion next to the heated band is not harmful. There may be other restrictions or different formulae involved, and the relevant Code must be checked.

Partial Heat Treatment

There are occasions, for example with very long vessels, when the entire vessel will not fit into a fixed furnace. This has been catered for in most Standards, and it is permissible to post weld heat treat section of the vessel first, then turn the vessel around and heat treat the remaining section. As with local heating, there are restrictions in this case as well over the degree of overlap and the longitudinal temperature gradient. AS 4458 requires an overlap of at least 1500mm, and care should be taken to ensure that this section does not contain a weld which may be post weld heat treated twice. Generally, there are better ways to post weld heat treat vessels than to use this partial method.

Thermocouples

For the temperature ranges applicable in this guidance note, ie. up to 750^0 C, the normal chromel-alumel thermocouples perform in a satisfactory manner. They can be purchased either as insulated wires or as sheathed units. The wire type are better in that they can be attached directly to the equipment being heat treated by capacitor discharge. The sheathed types need to be physically attached, often by welding a drilled nut onto the equipment and bolting the sheath into the nut. There is an argument that says this measures the atmosphere temperature just above the nut and not the metal temperature, but the basis of the argument is tenuous at best.

The number and placement of thermocouples is also governed to a certain degree by Standard requirements. For example, AS 4458 stipulates that the maximum variation in temperature within the component shall not exceed 140^0 C within any 5 metre length. EN 13445 stipulates a maximum variation of 150^0 C within a 4500mm length, but restricts this to 100^0 C when the temperature exceeds 500^0 C. Sufficient thermocouples therefore need to be attached to demonstrate that this requirement is met. Allowance should also be made for breakage and thermocouple malfunction, so it is normal to attach more than just the minimum. For internally fired vessels and locally heat treated weld seams, for each thermocouple attached to the outside, there should be a corresponding one on the inside. There is also a requirement for locally heat treated weld seams and partially heat treated vessels to measure the temperature at the edge of the heating band to ensure it is at least half of the peak temperature. For vessels where there are differing material thicknesses, thermocouples should be placed on all thicknesses, irrespective of the 5 metre length.

Heating/Cooling Rates

These are specified in most of the construction Standards, and are reasonably similar. For example, AS 4458 for carbon manganese steel vessels limits heating and cooling rates to 200^0 C/hour for thicknesses up to 25mm, and 5000^0 C/hour divided by the thickness for vessels over 25mm. There is also a minimum limit of 50^0 C/hour for very thick vessels. However, for ½Cr½Mo¼V and 2¼Cr1Mo alloys, the heating rate is limited to half that of carbon manganese steels. For comparison, EN 13445 allows 220^0 C/hour up to 25mm thick, 5500/thickness for 25 to 100mm and 55^0 C/hour above 100mm thick. There are no restrictions on the alloy steels in EN 13445.

By the time the holding temperature has been reached, the variation in temperature between any two thermocouples should not exceed the range specified for the material. In AS 4458, the range is typically 40^0C (eg. C-Mn steel range is 580 – 620^0C), and in EN 13445, it is 50 – 70^0 C. In most practical situations, the variation can be limited to much less than this.

The issues described here are vital to avoid post weld heat treatment going wrong and the result being a scrap vessel. It is recommended to all fabricators to obtain a post weld heat treatment procedure from a heat treatment company, where all of the above-mentioned restrictions are spelled out, before starting.

Test Pieces

There are two main types of test piece that accompany pressure vessels through the post weld heat treatment cycle. In most countries, they are the Production Test Plate (PTP) and the Coupon Plate. The PTP contains a weld seam, and is either a run-off plate from a longitudinal weld, or a weld done in parallel to represent a circumferential weld. The Coupon Plate is usually an off-cut of parent material, and is used to follow the vessel through all heat treatment cycles, including hot forming, normalising and post weld heat treatment.

It is highly unlikely that such test pieces would be needed where local post weld heat treatment has been applied. Test pieces are therefore limited to furnace heat treated vessels. Most Standards require that the test piece(s) accompany the vessel through the actual heat treatment cycle, and will not

allow a simulated cycle (AS 4458 is an exception).
For internally fired post weld heat treatment, the test pieces must be placed inside the vessel, but with furnace methods, they may be placed inside or outside the vessel. Care must be exercised with the location, since the test piece must be subjected to the same heating and cooling rate as the vessel. It is also critical for each test piece to have a separate thermocouple attached.

Charts and Certificates

No post weld heat treatment should ever be performed without a chart generated by a correctly calibrated recorder. The chart is proof that the post weld heat treatment was carried out correctly, and forms part of the Manufacturer's Data Report. In many countries, the Third Party Inspector is required to witness the loading of the furnace or the set-up in local methods, and actually sign the chart. In Australia, this is not required, but a senior member of the Company performing the post weld heat treatment should sign the chart.
A Certificate of post weld heat treatment is also often issued, describing the equipment and giving details of job number, etc. but this should be complimentary to the chart, not a replacement for it.

Non-destructive testing

EN 13445 requires that all non-destructive testing be carried out after post weld heat treatment. There is a modification that allows for material that is not sensitive to heat treatment cracking to be examined before post weld heat treatment. These materials include carbon manganese, carbon molybdenum and 1¼Cr½Mo steels, but the customer should be consulted before assuming non-destructive testing may be done before post weld heat treatment.
Of the American Codes, ASME B31.3 is probably the most widely used in Australia. It is slightly more restrictive than it's European counterparts in that only carbon manganese steels can be tested before heat treatment, and all alloy steels must be tested afterwards. In this regard, ASME 1, VIII Div.1 and VIII Div.2 are all similar to B31.3.
AS 4458 refers to AS 4037, and this again allows testing before or after post weld heat treatment depending on the alloy. Restrictions to testing after heat treatment apply mainly to high alloy steels such as martensitic, austenitic and ferritic types, as well as the ½Cr½Mo¼V steels. There is a further restriction for 9%nickel steels and quenched and tempered alloy steels in that there has to be a 7 day delay between post weld heat treatment and magnetic particle testing, and that this testing must also be done after hydrostatic testing.
It is strongly recommended that fabricators fully understand the requirements of the contract and the particular requirements of the Standard before establishing their inspection and test plans.

OMISSION OF POST WELD HEAT TREATMENT

There are a 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.

In some States in Australia, the use of AS 3788 is mandatory, and in the others, it is used extensively as a guideline. This standard, in paragraph 6.2.1 makes a clear statement that all repairs shall be carried out in accordance with the relevant design and fabrication standards. It goes on to state in paragraph 6.2.2 that minor repairs may be carried out only for those materials and service conditions, or both, which do not require any post fabrication heat treatment.

Standards in other countries, eg. the National Board Inspection Code in the United States, make similar statements. At first glance therefore, any repair, alteration or modification to an item of pressurised equipment that was originally post weld heat treated after fabrication needs to be post weld heat treated again after repair. This is not always possible, and efforts over the past 20 years have been aimed at finding ways around this.

Cost Advantages

Whilst most repairs that are contemplated could be post weld heat treated, even if it means removing the equipment to a workshop, the cost of doing so becomes prohibitive in today's economic climate. There are other situations, notably in the Nuclear Power industry, where removal of equipment is simply not possible. Therefore, in terms of risk management, there has been a strong drive to develop techniques to eliminate the need for post weld heat treatment following an on-site repair.

Technical Advantages

This is quite an emotive issue, and like statistics, any number of conclusions can be drawn from sets of data. Of the effects that post weld heat treatment has on a weld, residual stress will obviously remain if post weld heat treatment is waived, 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 waiving post weld heat treatment on technical grounds should not be confused with economics.

TECHNIQUES FOR WELD REPAIR WITHOUT POST WELD HEAT TREATMENT

Attempts to achieve satisfactory results from weld repairs where post weld heat treatment has been omitted are not new. Much of the original work carried out for the Nuclear Industry began in the early 1980s, and Code Case N-432 for a limited range of materials under ASME III in the United States was established in 1986. Since then, the various techniques have been refined and adopted into other standards such as ASME B 31.1, B 31.3 and even ASME XI. Some of the better known techniques will be examined in more detail.

Half bead technique

This technique was developed using the shielded metal arc (SMAW) process and was essentially aimed at providing an alternative to the use of post weld heat treatment. The technique was originally developed for use in the nuclear industry, but has since become widely used for repairs to piping, headers and turbine casings in conventional power plant and other industries. The SMAW technique usually employs the use of increasing diameter electrodes, starting with a 2.5 mm, then a 3.2 mm and finishing with a 4.0 mm.

The area to be repaired is preheated to a temperature commensurate with the material and thickness, and a buttering technique used as a first layer with the 2.5 mm electrode. The purpose is to produce a small, shallow heat affected zone. The next step is to remove approximately half of the thickness of each run by grinding. The second layer deposited using 3.2 mm electrodes effectively re-transforms the coarse-grained heat affected zone and first layer, and the third pass with the 4.0 mm electrode further tempers the heat affected zone. Each subsequent layer transforms and tempers the layers beneath in the normal way.

The major advantage of the technique is that the toughness of the heat affected zone is considerably improved over conventional methods, but the disadvantages include the fact that a lot of grinding is required, and accurate grinding at that. Not only is this time consuming, but if too much material is removed from the first layer, the effects of the re- transformation may not be as successful as might be expected.

Consistent layer temper bead technique

This technique utilises either the SMAW or the GTAW process, and was developed by EPRI in the early 1990s to ensure that toughness properties in both the heat affected zone and the weld metal were at least equal to the toughness properties of the original base material. The technique involves depositing weld layers that are sufficiently thick that the subsequent weld layer only tempers the heat affected zone caused by the first layer. The temperature is not intended to exceed the A_{C1} so no grain refinement occurs, and the effect is essentially similar to a post weld heat treatment. The technique produces a heat affected zone microstructure that consists predominantly of tempered martensite with small amounts of bainite, resulting in good toughness properties.

Alternate temper bead technique.

This technique was also developed under the EPRI program but specifically for carbon-manganese and carbon-molybdenum materials used in nuclear reactor pressure vessel components. It utilised the automatic GTAW process and was an alternative to the half bead technique for use in areas of high radiation exposure. The technique involves preparing the area to be repaired so that at least six buttering layers can be performed. A preheat of 150^0 C minimum is applied, and the heat input of each layer is controlled to within 10% of that measured in the procedure qualification test. If more than six layers are used, the same control over heat input is required. The final step is a low temperature post weld heat treatment at 230 – 290^0 C.

The aim is to produce tempering using several weld layers so that each subsequent layer penetrates the previous layer to develop overlapping temperature profiles. However, the A_{C1} is exceeded, resulting in re-transformation and grain refinement of the heat affected zones. Sometimes, different heat inputs are used for the first three layers, starting with a low heat input to minimise the extent of the heat affected zone in the parent material. The heat input for the second layer is increased to give a slightly thicker deposit whilst still re-transforming the parent heat affected zone, and the third layer is still thicker to ensure tempering only of the heat affected zone.

Controlled deposition technique.

This technique resulted from special cases where creep embrittlement and reheat cracking were potential problems during repair, and was aimed at specific materials used in conventional fossil-fired stations. It is also a SMAW technique, and uses strictly controlled ratios of heat input between one weld layer and the next. The heat input for the second layer is 1.3 to 1.8 times higher than for the first layer, and is designed to produce grain refinement and tempering in the original heat affected zone. The ratios need to be experimentally verified for each material to be welded. The technique eliminates the coarse grained region within the heat affected zone where creep cracking and reheat cracking have caused problems in the past.

DECISIONS ON REPAIRS

Most decisions regarding repairs to pressurised equipment in large, complex plant are made using risk management principles. On the one side of the risk management equation is consequences of failure, and this can be financial, environmental or health and safety related. Once an item of equipment has been found to contain a flaw of some description, the consequences of

- Doing nothing,
- Repairing the flaw,
- Replacing the item,

need to be considered. If the decision is to repair, the consequences of the repair method also need to be evaluated. The decision to repair must be made by the Owner/Operator, who should also take full responsibility for the consequences of the decision. Decisions on the repair method are more difficult. This is because in today's climate, plant maintenance is often subcontracted, and the subcontractor does not always have the knowledge to advise on repair consequences. The issues here tend to be as much legal as technical, but again, the Owner/Operator must take responsibility for ensuring the correct advice is sought. In certain industries, there are sufficient Institutions (eg EPRI and UKAEA) and people within those Institutions with the knowledge and experience to advise on the likelihood of success. In other industries, this is not the case, and more is said of this issue below.
On the probability of failure side and the attendant risks, repairs where post weld heat treatment has been omitted is reasonably mature technology. In the power generation and nuclear industries, there is sufficient evidence to show that carbon-manganese, carbon-molybdenum and chromium-molybdenum steels operating at high temperatures can be safely repaired. One outstanding problem is the question of properties when a defect is found in a temper bead repair and a fracture mechanics assessment has to be carried out. A review of the literature shows that very little K_{1C} testing has been carried out. The charpy impact testing that has been done has been done on the heat affected zone. If a defect is in the weld repair, this immediately takes any calculation into the realms of probabilistic fracture mechanics.

In other industries such as Petrochemical, the technology is probably less mature. There are some instances where the temper bead technique has been used quite successfully in non-sour service. Whenever NACE MR 0175 restrictions apply, repairs without post weld heat treatment have almost universally resulted in cracking of the repair at a later date. This is quite obviously the result of residual stress.

QUALIFICATION OF WELDING PROCEDURES

In just about every world Code or Standard, the application of post weld heat treatment is an 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 post 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 an 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 50mm shell plate would normally only have been held at temperature for 2 hours (ie. 1hour/ 25mm). In practice, that same vessel may have different shell thicknesses or even a tube plate, and the 50mm 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.

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