REPAIR WELDING HIGH-ALLOY FURNACE TUBES

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Repair welding high-alloy furnace tubes

Follow these guidelines for successful welding of aged castings

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ONE OF THE PROBLEMS faced by operators of high temperature reformer and pyrolysis furnaces is repair welding of damaged furnace tubes that have been exposed to elevated temperatures. The primary reason for the difficulty lies in the high carbon content of the common cast heat resistant alloy tube materials, such as HK - 40, the HP alloys, and others known for their superior high temperature properties. In the as-cast condition, the alloys have good ductility and are readily weldable. However, after the material is exposed to typical operating temperatures, some carbon is precipitated from solution in the form of "secondary" carbides, resulting in a dramatic loss of room temperature ductility.

Emphasis will be on the HP-modified group of alloys, as many consider field welding of these materials impossible or risky at best. In recent years the 25Cr/35Ni Cb alloy has been adopted as a standard for steam methane reformer and ethylene pyrolysis furnace tubes because of its high strength, higher temperature capability and good thermal fatigue resistance. There is virtually no information relating to the weldability of HP + Cb after exposure to elevated temperature. Recommendations will be provided to successfully restore ductility by solution annealing the base metal prior to welding, as well as information on the selection of welding filler metals and welding processes, and precautions to be observed.

Typical retrofit. The need to make certain modifications to the bottom of an existing reformer furnace tubed with 25/35 Cb offers a good illustration of a proper welding procedure. This information is of practical interest, because it is based on successful repair techniques used to make in-position field repairs involving aged HP-alloy tube-to-tube and reducers to 800H pigtail welds that are now in operation. A schematic is shown in Fig. 1 with a typical range of operating conditions.

In making sound and serviceable furnace tube repair welds, six factors have a significant effect:

1) Tube wall soundness of the aged HP reformer tubes determine the extent of stress rupture damage, oxidation and carburization
2) Effect of solution annealing in restoring ductility
3) Effect of filler metal selection on stress-rupture properties
4) Weld joint design and joint preparation
5) Effect of the welding process
6) Effect of welding techniques and sequences.

These factors will be discussed in detail.

Removing surface layers. Castings that have been in service are often oxidized or have metallurgically altered surface layers. All surface oxides must be removed by grinding or machining prior to welding to prevent defects. The oxides on alloy castings adhere tightly and can not be removed by hand or power wire brushing. Oxides of nickel and chromium are more refractory than the cast alloy, and melt at temperatures several hundred degrees higher than the base metal. Consequently, the oxides are not dissolved in the weld metal and may become entrapped in the form of sharp, notch-like defects.

Carburization is often a problem with castings used in the ethylene pyrolysis process. The deposition of coke on the inside of the tubes results in carbon absorption into the metal. Carbon contents of up to 4.5% have been measured on the carburized inner surface of cracker tubes. A massive quantity of metal carbide is formed and the chromium is depleted. The matrix in the carburized zone is enriched in nickel and nickel-iron alloy, and is ferro-magnetic.

The carburized layer must be removed prior to repair

TABLE 1—Typical room temperature mechanical properties of HP + Cb as cast and after elevated temperature

	Tensile strength (KSI)	Yield strength (KSI)	Elongation in 2 inches (%)	Charpy V-notch impact strength (ft lb)
As-cast	70	35	20	10
Exposed at 1,600°F for 1,000 hr	75	42	4	3

TABLE 2—Nickel alloy filler metal selection

	Service temperature, °F	
Welding process	Up to 1,600	1,600 and above
SMA (AWS A5.11)	ENiCrFe-2	ENiCrMo-3
GMA and GTA (AWS A5.14)	ERNiCr-3	ERNiCrMo-3 or ERNiCr-3

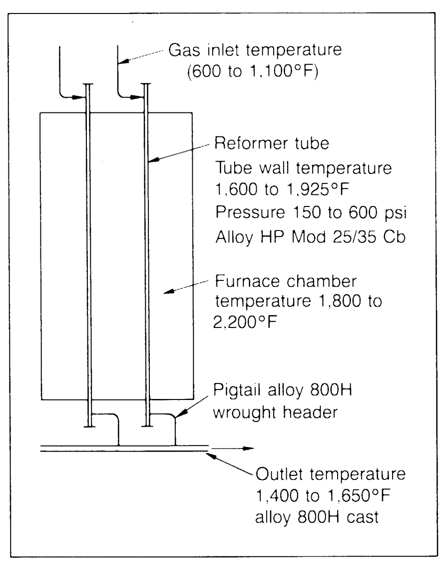

Fig. 1—Typical operating conditions.

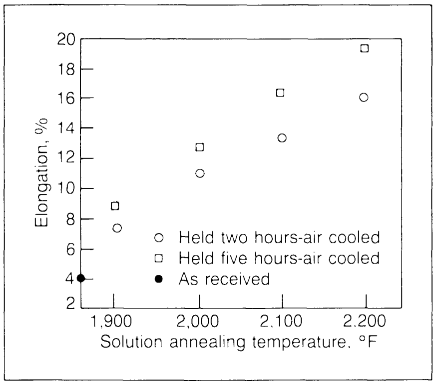

Fig. 2—Elongation vs. solution annealing temperature.

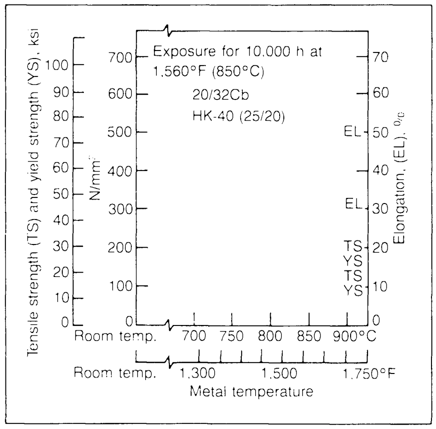

Fig. 3—Mechanical properties of HK-40 cast alloy 20/32Cb.

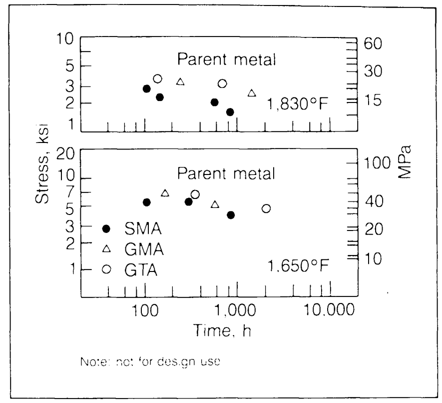

Fig. 4—Typical stress rupture curves.

welding. The layer is magnetic while the unaffected matrix is nonmagnetic. A magnetic inspection with a permeability meter or a spring supported magnet can give an indication of the remaining life of the tube and if repair welding can be attempted. The carburized layer should be removed by grinding or machining, at least 1/2-in. back from the edge of the weld. While removal of the layer reduces wall thickness, it should be realized that carburized metal no longer makes a significant contribution to the tube strength.

Need to solution anneal. Alloys such as HK-40 and 25/35 Cb have good as-cast ductility, but after exposure to furnace operating temperatures, there is a dramatic loss in room temperature ductility as shown in Table 1. Elongations as low as 1 1/2% have been reported in HK-40 castings after service.

HK-40 and 25/35 Cb castings that have been in high temperature service, require a solution anneal prior to repair welding or heat affected zone cracks are likely. A minimum solution anneal would be two hours at 1,950°F. Fig. 2 illustrates the benefit of longer times and higher temperatures in restoring ductility.

The 20/32 Cb alloy or the cast version of alloy 800H is used widely for outlet manifolds because of its high strength below 1,650°F and low embrittlement tendency. Elongation is 25% when new and over 15% in the aged condition. This is usually adequate ductility for low to moderate restraint welds. Comparative properties of HK-40 and 20/32 Cb are shown in Fig. 3.

Joint preparation. The weld joint end preparation is made by grinding or machining. The bevel angles and root radius vary with the welding process and whether it is a one or two side weld. In either case, it is good practice to provide a wider and more open joint than used in carbon or low alloy steel to allow for the more sluggish weld metal. The weld joint and heat affected zone should be inspected visually and with dye penetrant inspection to assure removal of defects prior to joint fit-up.

Elements such as sulfur, phosphorus and lead on the surface plus the heat of welding may cause embrittlement cracking of high alloy castings. The cracking may occur in the weld or in the heat affected zone. Since sulfur is often present in machining lubricants, it is good practice to machine dry, with no lubricant. Elements causing embrittlement may come from a number of sources such as marking crayons, paints, oil and common shop dirt. The weld area must be cleaned with a suitable solvent prior to assembly and welding.

In HK-40 and 25/35 Cb castings, carburization is decreased as silicon in the alloy is increased from 1.5 to 5.5%. Unfortunately, silicon decreases weldability and is normally restricted to a 1.5 to 2.2% level. A weldability test is often advisable to check the effectiveness of the solution anneal and a clean surface before starting to repair weld. This can be a simple test such as a bead-on-plate gas tungsten arc (GTAW), using filler metal, in a future heat affected zone (HAZ) area. The weld bead and HAZ is conditioned with fine abrasive and dye penetrant inspected. If cracks are found, it is an indication that the anneal or surface preparation was inadequate or that the casting is beyond repair.

Root pass welding. The root pass, or more specifically, the internal root surface is the most important portion of a weld in process piping since that is the surface most often exposed to the process media. The pipe ID is seldom accessible for touch-up welding so it is most important that the initial weld be of high quality. GTAW should be used for the root pass when the ID is inaccessible. An internal inert gas purge with argon or as an alternate, nitrogen, is needed to obtain an acceptable root contour free from oxidation.

The GTAW root pass may be made with or without filler metal. Shop fabricated weldments in new castings, where fit-up can be closely controlled, are often made without the addition of filler metal. However, field repair welding conditions are often less than optimum and usually call for filler metal addition, either by the hand feed filler metal technique or by consumable inserts. A consideration in the selection of the particular method should be the weldors past experience and preference. With proper skill, sound root pass welds are obtainable with either procedure.

Filler metal selection. Comparable composition welding filler metals are made for most of the cast alloys such as HK-40, 25/35 Cb and 20/32 Cb. The product forms include covered electrodes for SMAW and bare filler metal for gas metal arc (GMA) and GTA welding. The producing foundry may be a source of welding products and should be contacted, particularly for special cast alloy modifications. The bare filler metals are usually more available from foundries than SMA electrodes. HK-40 type electrodes are produced by a number of U.S. manufacturers but this is not true for 25/35 Cb and 20/32 Cb. European manufacturers have been more flexible in producing a range of welding consumables for casting alloys.

A common misconception is that a weld made with a comparable composition welding product has the same stress rupture strength as the cast alloy. This is not the case. In fact the welds may be considerably weaker than the castings. Fig. 4 illustrates the difference in typical stress rupture strength between 25/35 Cb castings and comparable composition GMA and GTA welds. There are similar differences between HK-40 and 20/32 Cb welds and castings. Long time stress rupture data of welds is limited. Cast alloy stress rupture data is widely available to 100,000 h while weld data to 10,000 h is sparse. Some general guidelines about high temperature weld properties are:

- GTA and GMA welds have substantially better stress-rupture properties than those made by SMAW. The former normally are about 80% as strong as the castings. GTA welds are usually stronger than GMA welds and with special techniques, welds with at least 90% of the alloy strength may be obtained. SMA welds often have strengths 60% or less than comparable composition castings.

• The difference in rupture strength between a cast alloy and comparable composition welds increases with increasing temperature.

An alternate to the use of a comparable composition is one of the nickel alloy welding products. Suggested types, based on service temperatures, are shown in Table 2. The EniCrMo - 3 welds have equal or better strength than 25/35 Cb at 1,650°F, but somewhat lower strength at 1,830°F. The nickel alloy welding products, particularly the covered electrodes, usually have an operability advantage which in turn helps minimize weld defects. One caution regarding the higher nickel alloy welds over 50% nickel is they should not be used in sulfur containing environments over 1,500°F. The presence of sulfur in both the feed stock and fuel oil should be checked before using the nickel alloy products.

Welding technique. If possible, all welding should be done in the flat position. The flat position aids in producing higher quality welds and allows higher deposition rates. The GMA process is widely used in fabricating new furnace components but is less used in field work. In the field, it is most common to make the root pass by GTAW and complete the joint by either SMAW or GTAW.

Many of the covered electrodes have a lime type coating. Welds made with the lime type are more crack resistant than those with the titania coating and preferred for repair of petrochemical equipment. However, with the lime type coating, a higher bead contour is obtained and some electrode weaving (not to exceed three times the electrode core diameter) is helpful in tieing beads together and eliminating locked-in slag. The alloys are susceptible to crater cracking and care must be taken to fill the weld crater before breaking the arc. All slag is removed between passes and from the finished weld with a hammer and/or stainless steel wire brushes. Residual slag is very corrosive to the alloy at high temperatures.

Other guides to repairing. Since the stress rupture strength of welds is often lower than the casting, where practical, welds should be located in areas of lower stress and away from corners or notches. This rule is normally followed in new fabrications but may be overlooked in retrofitting. Welds should blend with the castings and abrupt thickness changes should be avoided. Differences in heating and cooling rates between thick and thin sections can contribute to thermal fatigue failures.

Peening of welds is controversial. A major problem with peening is that it is difficult to specify the amount of peening. However, it can be a powerful aid in reducing weld stresses and may make the difference in whether low ductility castings can or can not be repaired. When performed, it must be done after each bead while the bead is still hot. A guide to an adequate force is that needed to give the weld bead a shot blast appearance. Only the fill passes should be peened, never the root.

Buttering the face of a bevel on a low ductility casting reduces the chance of cracking in the heat affected zone, particularly when a nickel alloy filler can be used. The weld metal has higher ductility and is deposited under minimum restraint conditions. One or more layers are deposited and the bevel remachined. The buttered weld layer is better able to absorb deformation when the butt weld solidifies. This technique may make the difference between success and failure when solution annealing is impossible.

Preheat is usually not used. However, if the section size is over 3/4 in. in thickness, the alloy may be preheated to 200 to 400°F. Usually no post weld heat treatment is required. Limiting interpass temperature is helpful for castings that have been in service. Cooling between passes to 250°F on resolution annealed used castings, and 150°F on used castings not solution annealed, is suggested. The interpass temperature guide would take precedence over preheat.

When castings are not worth repairing. There is a point where castings have deteriorated to the extent that weld repair is not practical, except possibly as a temporary measure until a replacement is available. One example is in ethylene furnaces when the inside of tubes are heavily carburized. When the tubes are cracked and leaking with fissures penetrating the wall or experiencing severe bulging, the tube has usually been carburized through 1/3 to 1/2 of the wall thickness and is beyond repair.

Thermal fatigue cracking in metal subject to temperature cycling may also make repair impractical. Thermal fatigue cracking may start as surface cracks, often in a checkered pattern. However, the damage also may be quite extensive internally, with only occasional surface cracking. Where thermal fatigue cracking has taken place, it is necessary to assess the extent of damage by grinding and dye penetrant inspection to determine the depth of cracking and if repair is feasible.

Creep damage in the form of cracks may be present in furnace tubes, particularly when operated above design parameters. The tubes will bulge from creep and when they have expanded by 2 or 3%, they should be replaced. Other structural damage to the base metal, such as severe oxidation or sulfurization, may make repair by welding unfeasible. An objective survey to determine if repair is practical often saves time and money in the end.

Recommendations for repair welding. Repair welding of high temperature reformer and pyrolysis furnace tubes can often add years of life if proper procedures are followed. To tell a weldor simply to "weld it up" is courting trouble and early failure.

While the emphasis here has been on HP + Cb, the same guidelines and precautions are applicable to other high strength, high temperature alloys.

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