Welding of fully Austenitic Steels for service at elevated temperature

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Introduction :

Fully austenitic steels as wrought and cast alloys are widely used in petro chemical and fertilizer industry for steam reforming processes and urea services. Austenitic 18-8 stainless steels are regarded as readily weldable steel without any risk of hot cracking by the addition of certain percentage of ferrite in the weld metal but fully austenitic steels are very crack sensitive. This crack sensitivity can not be reduced by the addition of ferrite because presence of ferrite at elevated temperature will promote formation of sigma phase which not only causes embrittlement but also reduces the strength and ductility remarkably. This paper will give an overall idea about the welding processes, materials & the weldability of fully austenitic cast and wrought alloys which are used for service at elevated temperature and pressure and for highly corrosive media.

Cast Austenitic Steels :

Cast austenitic steel has won increasing recognition in hydrocarbon and steam reforming processes as material suitable for use under stress at elevated temp. The main applications of these materials are in the reformer tubes, calcining tubes, furnace elements and heat treatment parts etc. Main advantages of the cast alloys over wrought ones are economy and higher rupture strength at elevated temp. and pressure. In recent years, centrifugally cast 25/20 cr-Ni steel, ACI alloy HK40 which has the best rupture strength amongst other alloys has come into extensive use for high pressure reformer catalyst tubes & the materials have been selected and are in use for a number of steam cracking installations replacing wrought material in the interest of lower cost and higher service life of the tubes.

Comparison of 100,000 hr. rupture stresses of cast HK40 with AISI 310 is given below in the table.

Temp. °F	*Rupture stresses in P.S.I.*	
	*HK*40 *alloy* (*Cast*)	*Wrought AISI* 310
1400	6500	2640
1600	2900	1290
1800	1270	0650

The above table shows that HK40 is about twice as strong. Welding of HK40 alloy has been discussed in this paper.

Welding Processes :

Generally, root runs shall be done by the TIG process with argon gas as shielding and purge gas. Tungsten inert gas welding is a must for root runs during welding of the reformer tubes where inside of the tube is not accessible and deslagging is not possible.

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Manual arc welding with coated electrodes is recommended for the subsequent passes, due to lower heat input. All slag must be removed from the weld surface-otherwise corrosion may occur. Recently autometic TIG welding of cast HK40 reformer tubes in which tube rotates has been successful. Stress rupture strength of welding joint (butt) is between 80-90% of the mean rupture strength of the cast parent metal when employing a deposit of matching composition.

Joint Preparation:

1. All joint preparations of butt weld shall be of J type to avoid misalignment and distortion of the parts (especially when welded from one side only) to be welded and volume of weld metal deposited should be minimum. So stress in the weld metal is also minmum.

2. All sources of carbon pick up by chromium in welding such as oil, grease, excess acetylene, cellulosic electrode coating and carbon electrode should be eliminated.

Typical joint preparation of a reform tube is given below:

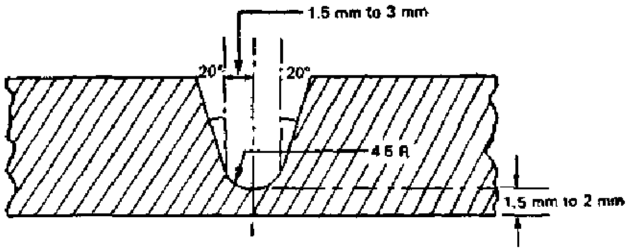

Table (1) & (2) will give the welding variables.

Table: I Inert gas shielded Tungsten arc root pass

Heat Treatment:

No heat treatment is required for cast alloys.

Electrodes & Filler Rods :

Before discussing the filler metals, it is better to know the chemical composition of HK40 alloy to understand its metallurgy fully.

Chemical composition of HK40 for reformer tubes is given below:

C < .35 to .45%	Cr < 24-27%
MN < 2% Max.	Ni < 19-22%
Si < 1.5% Max.	Mo < .5% Max.
P < .03% Max.	
S < .03% Max.	

C/Si ratio is maintained in such a way as to have maximum rupture and creep strength and sigma phase precipitation will be minimum.

Electrodes :

Welding of cast aust alloy with wrought alloy wire which contains .1%—.2% C is not possible and shows weld fissures because the casting contains approx .5% C and there is a great difference in hot strength and ductility between the two alloys. Any attempt to weld with low carbon wrought electrode will fail and show weld fissures. Substitution of matching filler metal with .5% C solves the problem.

One brand of this type of electrode is ESAB-exp 2936.

Root pass	Tungsten Size mm	Filler rod mm	Amperage	Voltage	Gas cup	Ar m³/hr weld	Purg Ar M³/hr
1	2.25	2,25	70-120	10—12	5	.6	.3

Table II

weld passes. to depth of m.m.	Electrode Size in m. m.	Amperage	Voltage	Purg Argon in M³/hr
6	2.25	70—80	15—18	3
12	3.00	80—100	-/- 19—21	Not required
20	3.00	100—120	10—21	,, ,,

Second filler material which is successfully used is the low carbon—High Ni alloys such as Inconel 182 & Incoweld A. These have good ductility and no problem arises during welding with these filler materials.

In TIG welding the filler rod material used are Inconel 82 & 92.

Function of the various elements:

Ni

1. Contributes high temp. strength promoting austenite.
2. Assists in reducing hot gas corrosion rates in oxidising conditions.
3. Increases carbonisation resistance.
4. It gives better hot ductility than Cr predominant alloy.
5. It gives lower thermal expansion coefficient than ferrite-free or predominant alloy. But 12% Ni or more increases high temp. corrosion rate in reducing gas atmosphere containing 100-200 grains of H_2S in 100 cuft at 900°C. Low melting Ni-S is responsible for this.

Cr It gives high temp. strength, high temperature oxidation resistance.

Relative merits of certain welding materials are given below based on some experimental facts.

	Metal Arc		TIG	
	Inco weld 'A'	Inconel '182'	Inconel 92	Inconel 82
1. Resistance to weld cracking	Good	Excellent	Moderate	Good
2. Liability to cause parent metal cracking	Moderate	Small	Moderate	Small
3. Susceptibility to pick up from parent metal	Moderate	Slight	Highly Susceptible	Slight
4. Availability	Good	Moderate	Good	Poor
5. Cost	High	Very high	High	Very high
6. Welding Characteristics	Good	Excellent	Moderate	Good

Nominal composition of weld metal with various electrodes and filler rods are given below:

1. ESAB. Exp. 2936	: C	=	.35—.45%, P=.04% (max), Si=2% (Max)
	Mn	=	1.5%, S=.04% max. Ni=19—22%
	Cr	=	23—27%
2. Inco-Weld A (Metal Arc)	: Ni	=	70%, C=.03%, Mn=2%
	Fe	=	9%, S=.008%, Si=.3%, Cu=.06%
	Cr	=	15%, Cb=2%, Mo=1.5% Ta=.03.
3. Inconel 182— (Metal Arc)	: Ni	=	67%, C=.05%, Mn=7.75, Fe=7.5%
	S	=	.008%, Si=.5%, Cu=.1%
	Cr	=	14%, Ti=.4% Cb=1.75%, Co=.08%
	Ta	=	.03%
4. Inconel 82 (TIG or MIG)	: Ni	=	72%, C=.02%, Mn=3%, Fe=1%
	S	=	.07%, Si=.2% Cu=.04%, Cr=20%,
	Al	=	.55%, Cb=2.5%

Si Is deoxidant and improves foundry characteristics. It improves carbonisation resistance of lower Ni grades such as HK40 alloy. It enhances oxidation resistance, and it improves corrosion resistance of cast heat resistant alloys in high sulphur reducing atmosphere.

C The effect of carbon is of importance primarily in wrought nickel. Commercially pure nickel contains .04-.07% C which is satisfactory for low temp. services. At elevated temperature, heat affected zones may in time become embrittled due to graphitisation and at higher temperature solubility of carbon is low (.02to.03%). Graphite present in the heat affected zones is dissolved, & held in super saturated solution due to rapid cooling and is later precipitated at service temp. in the form of intergranular graphite thus causing embrittlement. Solubility of C also decreases with increase in Ni %.

So C content should be kept as low as possible in weld deposit. C has a strong effect in fully austenitic steel, the cracking sensitivity being low for C .02% and increasing with carbon content to maxm. C=.08%. For C .2%, the danger of carbide precipitation dis-appears.

Cu Alters the high temp. solubility of C sufficiently to eliminate graphite embrittlement behaviour in the heat affected zone.

Fe It is introduced as ferro alloy.

Cb, Ti (i) Act as stabilisers to insure Cr depletion through carbide precipitations in weld heat affected zone.

(ii) Molten Ni dissolves gases which are released during solidification causing porosity. N_2,CO_2, Co, oxygen are most dangerous gases—So filler metal containing Ti as gas fixing element is used.

(iii) Cb is added to control the adverse effect of Si, when % Si is high.

Mn Prevents hot cracking and micro fissures.

Al acts as a deoxidiser to avoid porosity.

Repair Welding of Cast Materials

Repair welding of cast tubes is not recommended. The cast alloys are initially largely supersaturated solid solutions with ample ductility for welding in most of the cases. So welding is easy. After carbide precipitation has occured in service & specially carbonisation has also taken place, the ductility is lower. Welding without fissures is more difficult. So careful consideration of all metallurgical aspects may be required if good welds are to be made after castings have been in service. Before welding, we have to be sure that no carbide precipitation & carbonisation has taken place.

Wrought alloy

Fully austenitic wrought steels are widely used in outlet pigtail assembly of primary reformer furnaces, as heat resisting steels & against highly corrosive attack like urea services. The materials used for the above services are respectively Incoloy 800 (32 Ni-20 Cr.) AISI 310 (25 Cr.—20 Ni), AISI—316 L (Cr-18, Ni-12, Mo-3) which are fully austenitic steels.

Welding of Incoloy 800 Alloy in Outlet Pigtail Assembly

In reformer furnace, as the plant comes up to working temp. from cold, considerable relative movement occurs due to nonuniform expansion of furnace tubes & header system. This movement is accomodated by making the connection to the top & bottom of primary furnace tubes by lengths of wrought tubes (termed pigtails) bent into various forms to provide flexibility. Outlet pigtails are of wrought incoloy 800. Flanged joints are trouble some at outlet temp. and so the outlet pigtails are welded with furnace tubes & outlet headers through weldolets. Welding of furnace tube and headers with weldolet is generally done at workshop, whereas pigtails welding is usually made at site.

Welding Processes

To reduce the risk of slag entrapment, root runs of weldolets to furnace tubes and headers were deposited by TIG welding and subsequent runs by metal arc welding. Great deal of troubles were faced by root run cracking, root runs being too thin in relation to the surrounding masses of metal.

When the root run is accessible for cleaning, metal arc welding is recommended throughout and good penetration beads are obtained with electrode Incoweld "A". Small air driven carbide & wire brushes are used to remove the internal slag. Some pin points of slag may remain, but no troubles due to this have occure . But root runs of all weldolet to pigtails are made by Tig welding with Argon as purge gas (from inside of the tube) since the inside of the welding joint is not accessible & slag removal is not possible. Subsequent runs are made by metal arc welding. Inconel 82 is the filler metal used for root run welding.

AISI 316L & 310 are welded by metal arc welding with matching filler metal with limited ferrite content in the weld deposit.

Micro Cracking of fully Austenitic Steel

Micro cracking is also another problem during welding of fully austenitic steels. Weld metal may crack both during deposition & in underlying weld runs reheated by subsequent passes.

Susceptibility to these forms of cracking can be avoided by using consumables with such compositions that a small portion of the high temp delta ferite phase is retained in deposited weld metal. As stated earlier, in high temp., Ferrite may promote rapid transformation to the embrittling sigma phase. Solidification cracking is avoided by minimising joint restraint & heat input. However, whatever may be the mechanism of micro cracking, attempts have been made to minimise it by compositional control.

Mn reduces the microcracking, optimum content being 2—6% but does not completely eradicate the problem. But Mn. has a harmful effect on corrosion resistance particularly in moderately oxidising conditions when passivity has broken & the metal has become active.

However its complete avoidance in practice is therefore extremely difficult especially if as seems likely segregation of the alloying elements is contributory.

Welding Institute has recommended the following compositional control to minimise microcracking based on available data :—

1. c should be below .1%
2. Si should be .3%
3. S & P should be .015%
4. Mn. between 3 to 6% N is restricted to about .2%
5. Optimum Mo content 2.5 to 3%
6. Impurity elements should be as low as possible
7. Nb should be ∠ .3%
8. Basic M.M.A. welding electrodes coatings should be preferred

Another method to reduce micro cracking is the remelting of weld metal deposited from M.M.A. consumables using TIG process between each succeeding run.

Bibliography:

1. AWS Hand Book Vol .5.
2. Metal construction Vol. 7, No. 3 March 75.
3. A.S.M.E. Code Hand Book.
4. "Research back ground of thermoalloy grades of Cr-Ni-Fe heat resisting alloys" by H S.Avery.
5. Introduction to the metallurgy of cast heat resisting alloys" by A.R. Ward.
6. Welding Metallurgy of cast austenitic materials By R. G. Baker & D. M. Haddrill.
7. Welding of high alloy materials relevant to pressure steam Reforming of Naptha. By H. P. Hahn.
8. Fabrication of pigtail assemblies. By F.P. Hahn.
9. Metal construction, Vol-8, No-3, March '76.