308H & 16-8-2 STAINLESS STEEL WELD METALS FOR OIL REFINERY CATALYTIC CRACKING UNITS

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Welding Consumables for Heat Resisting Alloys

High Temperature Alloys

308H and 16-8-2 stainless steel weld metals

for oil refinery catalytic cracking units

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308H and 16-8-2 stainless steel weld metals for oil refinery catalytic cracking units

Figure 1: Modern Cat Cracker installation

1 Introduction

The first catalytic (cat) cracker came on stream in the USA in 1942, and these units have been continuously developed to the point where they now represent the world's major petroleum refining process. Over 400 units are in operation worldwide (Figure 1).

Parts of the cracker unit operate at high temperatures for long periods of time and the correct choice of parent materials and welding consumables is essential to ensure long life of critical components. Even with the optimum choice of materials, parts of the unit have a finite life and have to be repaired or replaced at intervals between 5 and 20 years depending on scale of damage and operating conditions. Many cracker units are shut down for a major refurbishment about every 4 years, and these opportunities offer scope for the introduction of welding processes and consumables which can improve both productivity during the shutdown and extend life during subsequent operation.

2 Basic design & operation of a fluidised bed catalytic cracking unit FCCU

The cracking operation is essentially very straightforward and a schematic diagram of a modern process unit is shown in Figure 2.

The cracking process takes place in the **reactor vessel** where hot oil, introduced with steam, comes into contact with hot catalyst in the form of a fluidised bed of fine particles; hence the system is referred to as a Fluidised Bed Catalytic Cracking Unit (FCCU).

A hydrocarbon mix of heavy crude oil feedstock and residues from previous distillation are broken down (cracked) to produce a range of lighter products including gasoline, jet fuel, light gas oil, etc.

After the reaction, the catalyst becomes partially deactivated by a layer of carbon deposited from the heavy feedstock, which needs to be removed by passing it into a **regenerator vessel**. In the regenerator vessel the catalyst is reactivated by mixing it with hot air and burning off the carbon. The carbon monoxide produced is then burnt to preheat the air and feedstocks, while the regenerated catalyst is recirculated back to the reactor vessel. The cracking process therefore proceeds on a continuous basis.

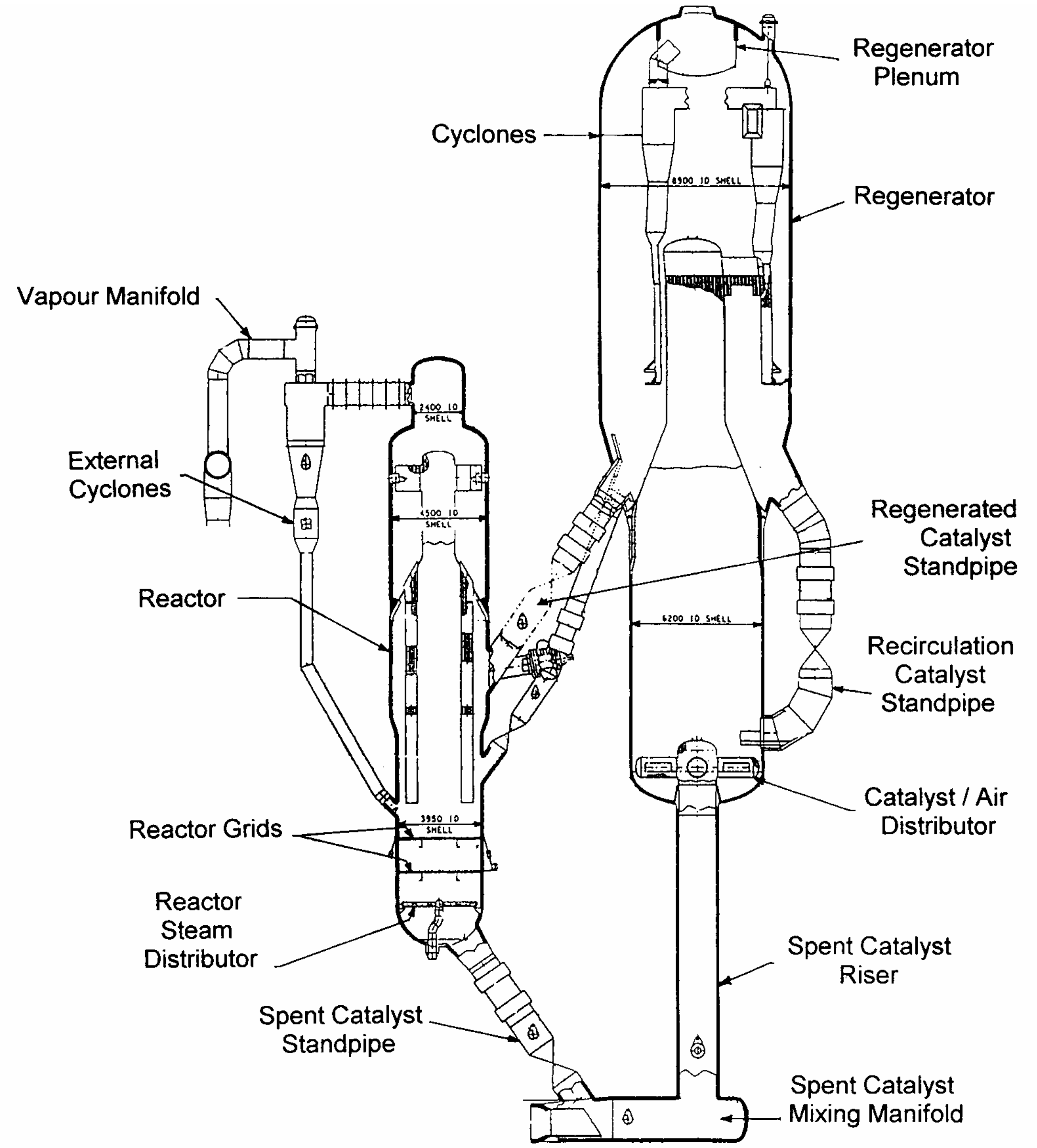


Figure 2: Recent (1998) design for cat cracker showing all major components. Note that catalyst recovery cyclones are external on the small reactor vessel (left) and internal on the large regenerator vessel (right).

3 304H type stainless steel components

A modern FCCU operates at high temperatures, 500-800°C (930-1470°F), but at relatively low pressures, 0.2–2 bar (3-30psi), and contains many tonnes of very fine, highly abrasive catalyst which is circulated through the system at high speed. The FCCU is made from a number of materials including plain C-Mn steels, and creep resisting Cr-Mo steels. These more economic materials are used where they can be protected from the extremes of temperatures and the abrasive effects of the catalyst by the use of refractory materials.

Where such protection cannot be utilised, more specialised alloys are used, e.g. Stellite for abrasive wear on slide valves and type 304H stainless steel for continuous high temperature exposure giving long term creep strength and oxidation resistance.

Items, which are often fabricated from 304H material and welded to a greater or less extent, include:

- **Regenerator cyclones** – contained within the regenerator vessel (Fig 3).
- **Reactor cyclones** – may be 304H or CrMo steels and may be located inside the reactor (older units) or outside the reactor (more modern units, see Fig 2).
- **Hot gas/catalyst transfer lines and stand pipes** – including expansion bellows.
- **Catalyst distribution system in the regenerator** – this may be an air-grid floor or a tubular manifold (Fig 2).
- **Various grids and components in the reactor vessel** – the exact location and design will depend upon the type of unit.

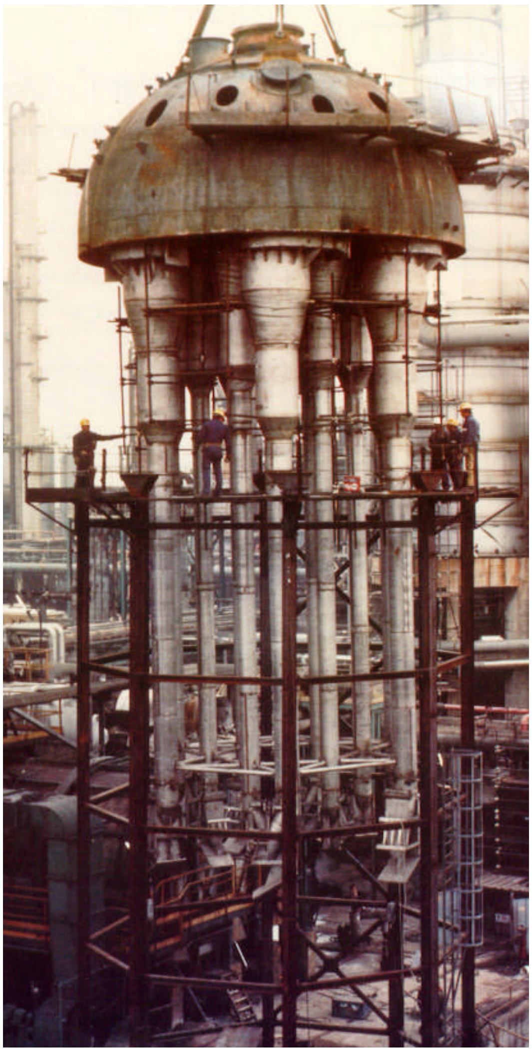


Figure 3: Regenerator vessel top assembly, complete with cyclones in position

- **Hexmetal** (Fig 4) – Hexmetal, which is like an expanded metal grid, is welded to the surfaces of vessels, cyclones, etc to act as an anchor for refractory cement. This refractory layer protects surfaces from extremes of heat and particularly abrasion.

  Various materials are used including 12/13 Cr stainless steels (type 410), 304H and some of the more exotic high temperature materials such as alloy 45TM.

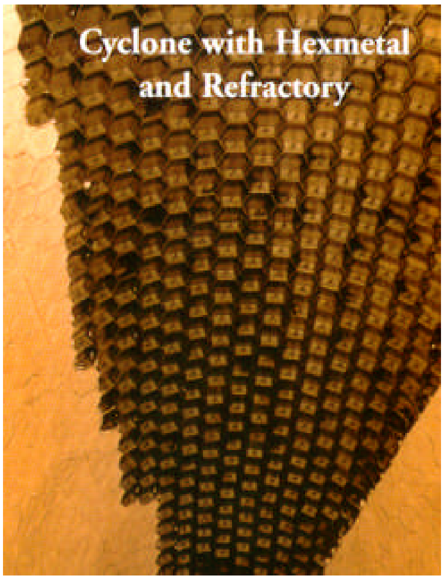


Figure 4: Detail of cyclone showing (a) hexmetal welded in position and (b) partially filled with refractory

Nickel base electrodes such as Metrode Nimrod 182 or Nimrod 182KS are usually chosen for dissimilar joints between hex-metal and the mild, CrMo, or stainless base materials but 308H consumables are used for matching materials.

4 Weld metal options for 304H material

4.1 308H Type Weld Metal

Many operators/contractors choose 308H type filler metal for welding 304H material. Close compositional control of wires and electrodes is maintained(1) to ensure:

4.1.1 Long Term Stability

The primary changes to which these alloys are prone, as a result of prolonged exposure to temperatures in the 500-800°C (930-1470°F) range, are sigma phase transformation and carbide precipitation. Precipitation of the intermetallic sigma phase is highly detrimental to ambient temperature ductility and toughness during low temperature shutdown conditions.

Carbide precipitation is an essential secondary mechanism ensuring elevated temperature strength and creep resistance. For this reason C levels are controlled in the range 0.04-0.08%.

4.1.2 Ferrite Control

Unlike the parent 304H steel, the 308H weld metals need a carefully controlled level of **ferrite phase** to ensure immunity from microfissuring or solidification cracking, particularly in the more highly restrained multipass welds.

In addition, ferrite refines the austenitic microstructure, which in turn promotes **creep rupture ductility**. However, at high temperatures, ferrite transforms rapidly to the brittle sigma phase, and is therefore limited to the range 2-8FN, which is compatible with compositions aimed to be "lean" within the specification ranges.

Metrode 308H TIG wire and MMA weld metal compositional limits, although intended to meet BS EN and AWS standards requirements, are more tightly controlled in specific areas to maximise elevated temperature performance:

C: 0.04 – 0.06%
Cr: 18.5 – 20.0% *
Mo (+Ti + Nb): 0.25% max
* For Metrode 308S96 solid filler wire, ≤ 20.0%Cr applies when specified to AWS ER19-10H, otherwise ≤ 20.5%Cr applies.

4.2 16-8-2 type weld metal

Some operators/contractors, and very especially EXXON/Esso worldwide, prefer the use of a "lean" version of the AWS 16-8-2 grade weld metal which is intended for welding matching 16Cr-8Ni-2Mo, type 316, 347 and 304H steels used for high pressure/high temperature piping systems.

Table 1 indicates the areas of "lean" compositional tightening specified versus AWS limits for standard 16-8-2 TIG wire and MMA weld metal.

Table 1: "Lean" 16-8-2 wires/electrodes compositional control limits

	C	Mn (1)	Si (1)	S	P	Cr	Ni	Mo	Cu	FN (2)
AWS min	-	0.5	-	-	-	14.5	7.5	1.0	-	0
max	0.10	2.5	0.60	0.03	0.03	16.5	9.5	2.0	0.75	9.5
"Lean"	0.04	0.5	-	-	-	14.5	7.5	1.0	-	1
16-8-2	0.10	2.5	0.60	0.03	0.03	16.5	9.5	1.3	0.75	6

(1) For solid wires the range is Mn = 1.0-2.0% and Si = 0.35-0.65%

(2) Estimated using WRC-1992 Diagram

Typical Metrode production batch control aims for:

Carbon: 0.04% minimum, to ensure adequate creep strength
0.08% maximum, to avoid risks of excessive chromium carbide precipitation during service and associated reduction in corrosion resistance.

Molybdenum has a important role to play in terms of:

High Temperature Creep

Molybdenum is beneficial to the creep rupture ductility of CrNi austenitic steels and, in high temperature plant, failures sometimes occur as a result of lack of ductility, rather than insufficient strength.(2) Although the effects are most marked when the performance of type 347 (Nb stabilised) welds are compared with those made from 316H consumables, there are benefits to be gained from the choice of a "lean 316H" type over 308H, because the Mo always improves high temperature cohesion of the grain boundaries and, hence, the ductility of austenitic stainless steels.(2)

Dew Point Corrosion and Oxidation Resistance

Weldments in austenitic stainless steels and nickel base alloys, which have not been stress relieved, can be sensitised after prolonged service at high temperatures, and become more susceptible to stress corrosion cracking (SCC). In FCCU environments the main corrosive compounds are aqueous solutions of polythionic acids which are formed when sulphidised surfaces are in contact with condensed moisture and oxygen during shut-down. The most susceptible parts are reactor/regenerator internals and flue gas lines and bellows.(3) The addition of even quite modest quantities of molybdenum provides significant protection.(4)

Although the lean composition (Cr+Mo) of 16-8-2 minimises the in-service formation of intermetallic compounds, molybdenum is restricted to avoid the risk of catastrophic oxidation in stagnant oxygen conditions.[3] For this reason, molybdenum content is typically controlled in the range 1.0–1.3%.

Ferrite Phase Control and Resistance to Hot Cracking

Unlike the parent 304H steel, type 16-8-2 weld metal is required to contain a controlled level of ferrite phase to ensure immunity from microfissuring or solidification cracking during the fabrication stage, particularly with the more highly restrained multi-pass welding of thick section components.

The appendices to AWS specifications recognise that 16-8-2 weld metals usually contain no more than 5FN. Experience indicates that solid wire typically may give no more than 0.5-1.5FN.[5] Nevertheless, despite the widely held view that ferrite above 3FN is required for optimum resistance to hot cracking in austenitic welds, experience indicates that 16-8-2 weldments are always sound.[6] Exceptional resistance to microfissuring has been demonstrated in E16-8-2 welds at 0.7-1.2FN in comparison with seven different 300 series weld metals.[7]

Another concern is the risk of solidification cracking of thick, highly restrained welds. A theoretical assessment can be based on the use of the Suutala Diagram [8], which essentially relates a combination of sulphur and phosphorus levels with the threshold for solidification cracking at a specific Cr equivalent / Ni equivalent ratio around 1.5 (Figure 5a). The deposit analysis of a number of batches of 16-8-2 FCW, which also had slightly higher S and P levels than the corresponding MMA electrodes, have been evaluated in the Suutala diagram. The prediction has been proved valid, with no solidification cracking being encountered even with highly restrained welds in 38 and 50mm (1.5 and 2in) 304H steel. (Appendix 1)

This favourable behaviour of 16-8-2 is evident from the WRC diagram (Figure 5b), which shows that the leanest compositions require little ferrite to achieve primary ferritic solidification (FA) although measured ferrites were a little higher than the WRC diagram predicts). The AF-FA boundary is equivalent to the Cr_{eq}:Ni_{eq} ratio of 1.5 on the Suutala diagram.

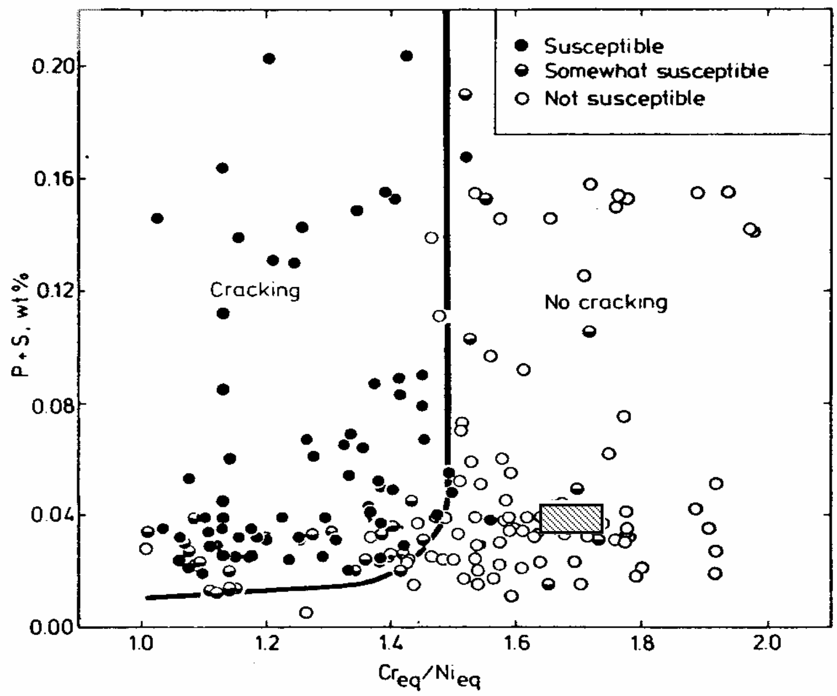


Figure 5a: Suutala Diagram showing position of 16-8-2 FCW weld metal in the "no cracking" region

Analyses of Supercore 16.8.2 FCW batches Cr_{eq} = %Cr + 1.37%Mo + 1.5%Si + 2%Nb + 3%Ti

Ni_{eq} = %Ni + 0.31%Mn + 22%C + 14.2%N

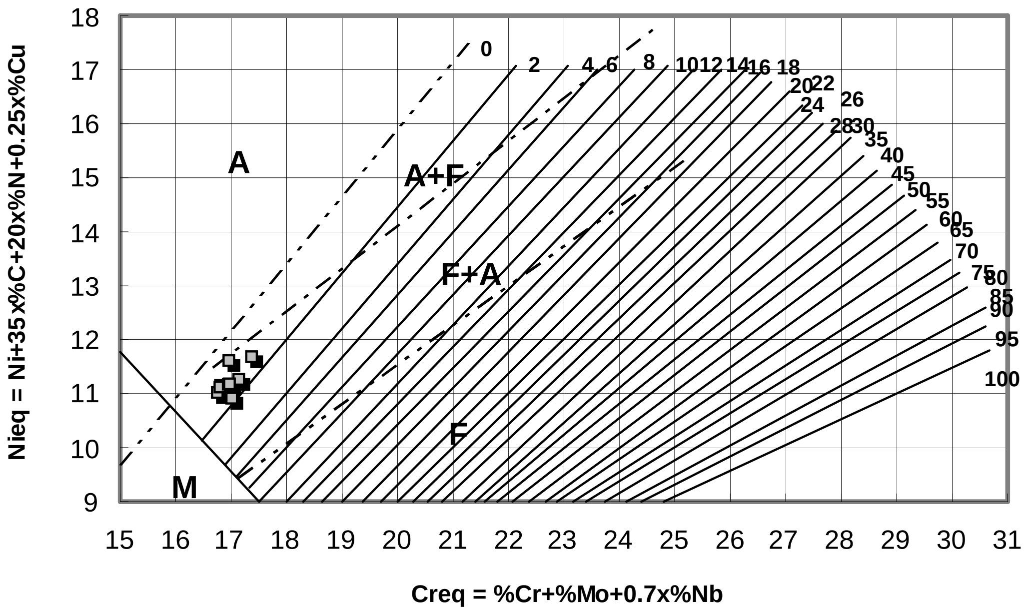


Figure 5b: Extended WRC-92 diagram showing the position of 16-8-2 FCW weld metal

5 The Metrode range of 308H and 16-8-2 consumables

The current programme of products available is given in Table 3. Individual Data Sheets for each of these products are included in Appendix 2.

Table 3: Metrode 308H, 16.8.2 and 347H welding consumables

	308H	***16-8-2***
TIG *(GTAW)*	**308S96**	**ER16.8.2**
MMA *(SMAW)*	**ULTRAMET 308H** (rutile, pipe/root welding)	**SUPERMET 16.8.2** (rutile, all-positional)
		ULTRAMET 16.8.2 P (rutile, pipe/root welding)
	ULTRAMET B308H (basic, all-positional)	**E16.8.2-15** (basic, all-positional)
MIG *(GMAW)*	**308S96**	Contact Metrode
	Gases: Ar + 2%O_2, Ar + 2 – 3% CO_2 or Ar + 38% He + 1 – 2% CO_2	
FCW *(FCAW)*	**SUPERCORE 308H/308HP** (rutile flux core)	**SUPERCORE 16.8.2/16.8.2P** (rutile flux core)
	Gas: Ar + 20%CO_2	
Sub-Arc *(SAW)*	**308S96**	**ER16.8.2**
	SSB Flux (basic, agglomerated)	

5.1 MMA (SMAW) electrodes

Metrode 308H and 16-8-2 MMA electrodes are used for the fabrication and repair of catalytic cracker structures, ducting and pipework in 304H stainless steels.

All the Metrode MMA electrode types incorporate the following features:

- controlled compositions to comply with national and international specifications – including C controlled in the range 0.04-0.06% for optimum high temperature properties
- ferrite controlled – usually in the range 2-8FN (aim 5FN max) – to avoid the risk of hot cracking/microfissuring, and at the same time minimise long-term service embrittlement
- both beneficial and detrimental minor elements are controlled to enhance long term, high temperature properties
- modern coating technology is employed to minimise moisture pick-up during storage, and so reduce the risk of porosity.

For the majority of work **Supermet, Ultramet** and **Ultramet P** rutile coated electrodes are entirely suitable:

- 2.5 & 3.2mm (3/32 & 1/8in) diameter electrodes operate satisfactorily in all positions and are suitable for welding fixed pipework. In particular the small diameter **Ultramet 308H** and the **Ultramet 16.8.2P** are optimised for positional pipe welding.
- in addition the 2.5mm diameter **Ultramet 308H** and the **Ultramet 16.8.2P** are specifically designed to enable the root pass to be deposited in single side butt welds using standard MMA equipment and without the use of purging gas.
- high radiographic quality welds
- micro-alloying enhances high temperature creep properties

For thick walled pipework, to be welded to the highest standards of integrity, fully basic coated versions are available, **Ultramet B**. These are capable of all-positional operability in all diameters and recommended for thicker section component welding in the ASME 5G (fixed horizontal) and 6G (fixed 45° inclined) positions.

5.2 TIG (GTAW), MIG (GMAW) & sub-arc (SAW) wire

The main applications for 308H and 16.8.2 type solid wires are for TIG welding and for Submerged Arc welding. The use of MIG appears to be mainly restricted to single pass fillet welding for hexmetal attachment and some overlays. Its use for shop fabricated major structural welds is limited and site applications are rare in the UK.

Wires for TIG welding

As far as possible solid wire compositions are controlled to match the MMA electrodes. In particular, carbon levels are maintained in the range 0.04–0.06% and ferrite levels are usually in the range 3–8FN. However, it is not always possible to produce solid wires with the same flexibility and controls as with coated electrodes. In the case of TIG welds which are largely used for root runs and smaller, less critical components, small variations from the optimum composition are not of great concern.

Wires for MIG welding

The wires used for MIG welding are exactly the same as those used for TIG welding, and the same comments apply

Where MIG welds are to be used for multi-run, high integrity applications, and where long-term properties are important, the consumable should be selected with care and, if necessary, the Metrode Technical Department should be consulted.

Wire/Flux combination for Sub-Arc welding

The wires used for Sub Arc welding are exactly the same as those for TIG and MIG welding. The Metrode SSB flux should be used; further details on the flux are given in the appropriate data sheet, Appendix 2. Wire diameter used would normally be 2.4 and 3.2mm (3/32 & 1/8in), and currents should be restricted to about 450A.

Ferrite control in SAW is particularly important. The increased risk of hot cracking / micro-fissuring, associated with larger size, higher heat input weld beads, is countered by an appropriate level of ferrite phase. However, excessive ferrite, and Si pick-up from the flux during welding may lead to long term service embrittlement.

It is strongly recommended that procedural trials are carried out with the intended wire/flux combination to ensure that the weld deposit compositions and ferrite levels are suitable for the intended application. The Metrode Technical Department should be consulted for procedural advice.

5.3 Flux cored (FCAW) wires

The use of flux cored wires to weld 304H material raises two significant issues:

5.3.1 The use of minerals in the slag system to enhance slag removal and bead appearance

Most manufacturers of 300 series stainless steel FCW's use bismuth mineral additives to give a slag-free bright deposit so characteristic of modern rutile type FCW's. However, these minerals have a significant detrimental effect on high temperature properties and in some cases have led to weld metal cracking and failure of key items. [9] [10]

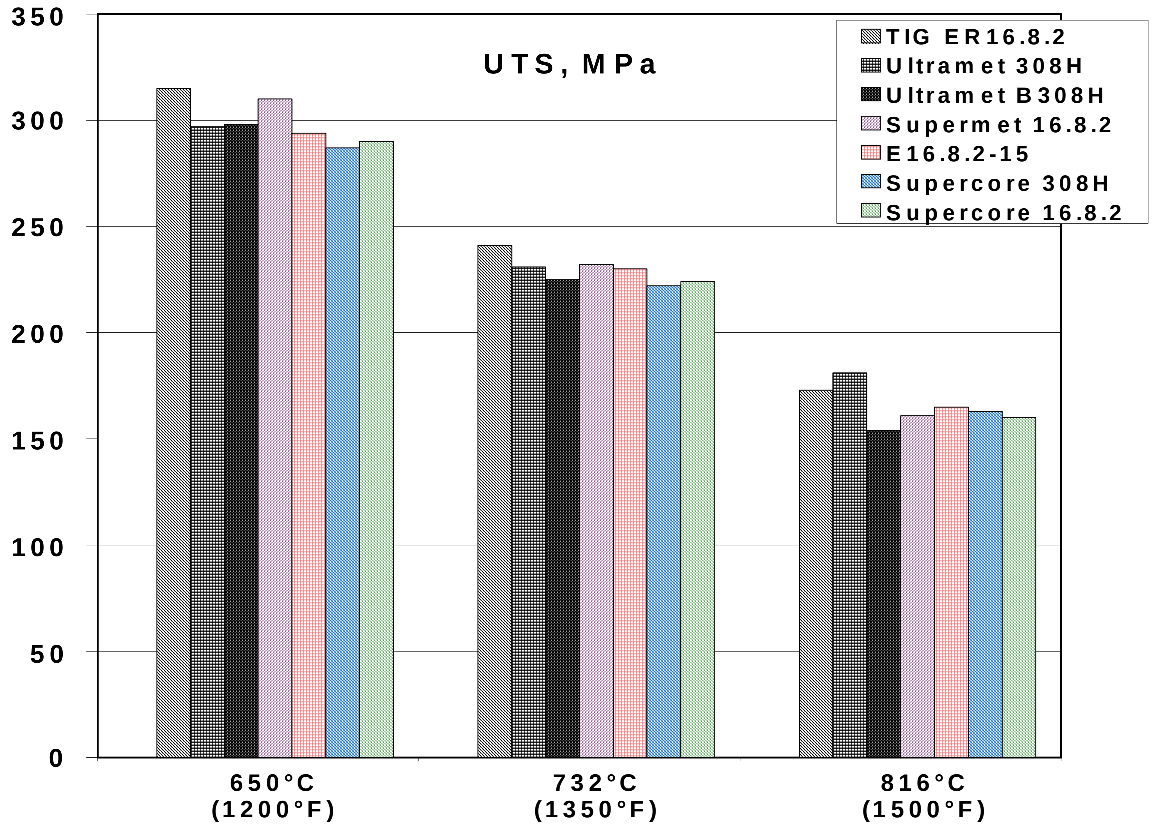
For this reason the Metrode FCW's (Supercore 308H / 308HP and Supercore 16.8.2 / 16.8.2P) have never contained bismuth mineral additives. The result is that the welds do not have quite the same bright appearance. However, slag removal is still very good, and the quality and long term performance of the welds is not compromised. A full review of this and a position statement has been issued by IIW, which gives a complete account of the IIW recommendation. [11]

As a result of the use of bismuth minerals by some consumable manufacturers a number of codes and specifications now impose a maximum bismuth level on the deposited weld metal. For example API 582 has a maximum Bi level of 20ppm (0.0020%) for flux cored wires. All of Metrode's high temperature 300H flux cored wires meet this requirement and Bi content is certified for each batch.

5.3.2 Will FCW deposits behave the same as weld metal deposited with other processes

There is a long and well-established track record with Metrode MMA electrodes, solid wires and submerged arc wire/flux combinations, but how do we know that welds made with FCW's will behave in the same way?

- The weld metal compositions are designed in the same way – with carbon, ferrite and undesirable residuals all controlled as with MMA electrodes.
- The flux systems used for MMA and FCW are quite similar and, of course, the deposited weld metal is not affected by which welding process has been used.
- Metrode have carried out hot tensile tests on both MMA and FCW deposits, and the results are given in Figure 6. From these it can be seen that there are no significant differences in tensile strength and ductility between MMA and FCW deposits.
- Metrode has carried out high temperature creep tests on weld metals deposited from 308H and 16.8.2 FCW's, and the results are reported in Section 6.



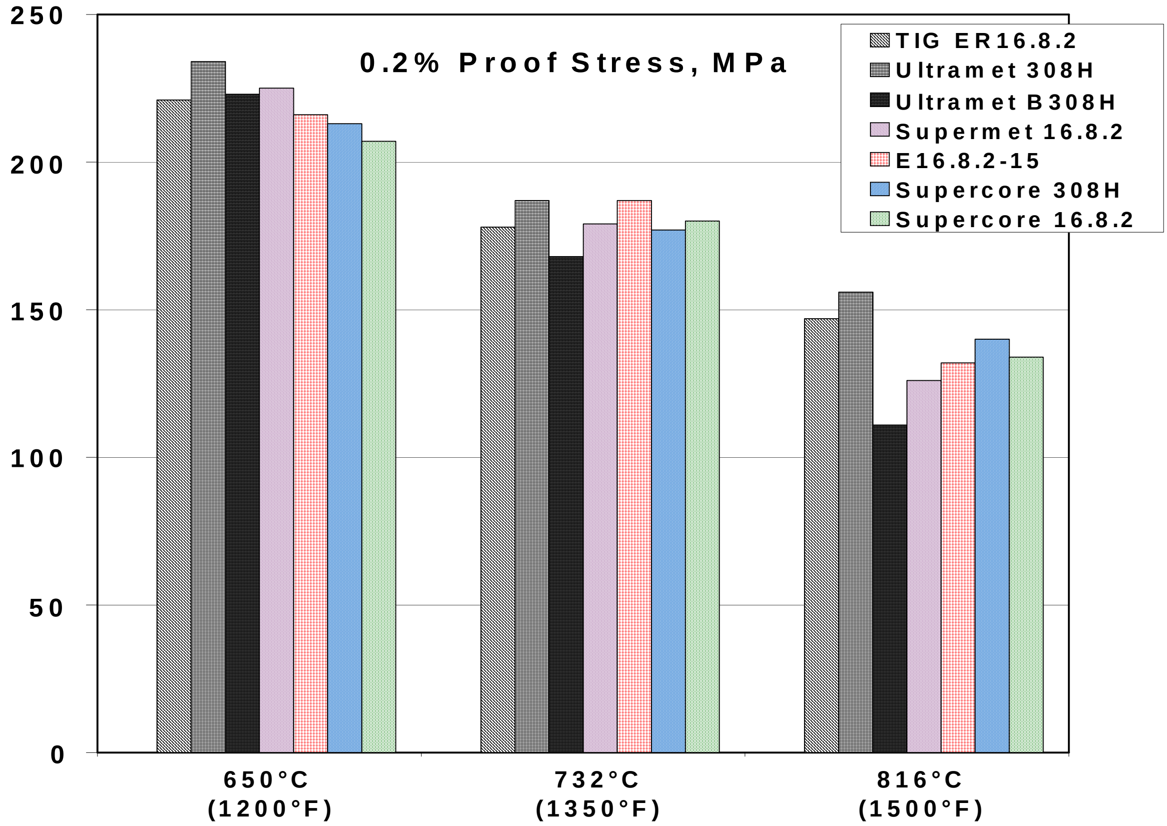


Figure 6: Elevated temperature strength and ductility properties of 308H and 16.8.2 from all-weld metal hot tensile tests

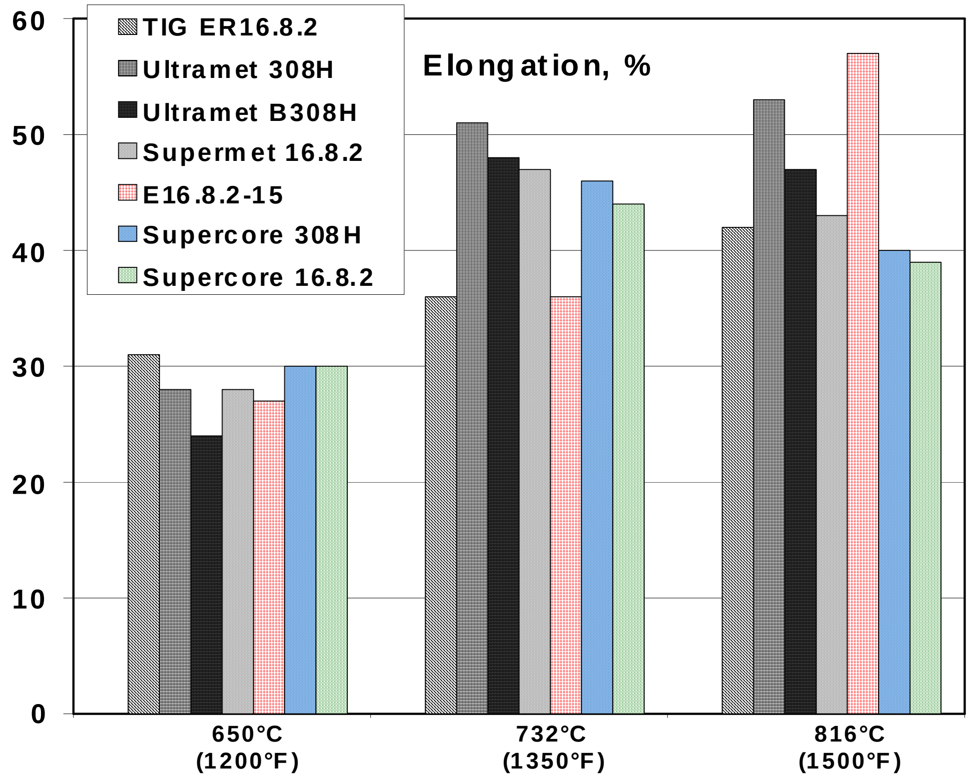


Figure 6 continued: Elevated temperature strength and ductility properties of 308H and 16.8.2 from all-weld metal hot tensile tests

6 Creep rupture testing

To complement the hot tensile test data given in Section 5.3, a creep testing programme on 308H and 16.8.2 type flux cored wire deposits has been carried out.

The results of the creep rupture tests are given in Table 4. The first two tests carried out at 650°C were unwittingly loaded to levels rather close to the 0.2% proof stresses of the respective materials at that temperature and consequently rupture occurred after very short periods. The tests are closer to hot tensile tests than time-to-rupture tests and therefore failure was premature and the results are of limited value. The remainder of the stress levels used and the resulting rupture times are all valid.

The stress-rupture results are shown as Larson-Miller plots to enable comparisons to be made with relevant parent materials, Figure 7. The data for Supercore 308H and Supercore 16.8.2 is plotted for comparison with curves derived from the minimum 105h rupture stress data for relevant 300H type parent materials. These curves represent the baseline from which ASME maximum allowable stresses are derived. The weld metals generally match or overmatch the minimum rupture stresses of all the parent materials, particularly at the higher Larson-Miller parameter values. This is also the case with 347H and 321H parent materials and therefore provides further justification for the use of 16.8.2 or even 308H consumables for welding these grades of steel.

Table 4: Results of creep tests (stress-to-rupture)

Consumable	Series	Temperature °C	Stress, MPa	Time, hours	R of A %
Supercore 308H	'100h'	650	210 *	9	68
		732	115	124	63
		816	55	227	37
		871	35	198	3.3
	'1000h'	650	160	1037	47
		732	85	750	23
		816	45	749	14
Supercore 16.8.2	'100h'	650	220 *	10	68
		732	130	39	64
		816	65	78	38
		871	35	303	4.5
	'1000h'	650	160	1027	58
		732	85	488	71
		816	45	861	23

* The stress applied for these tests was mistakenly high and approximates the 0.2% proof stress of the weld metals at the test temperature, see Figure 6.

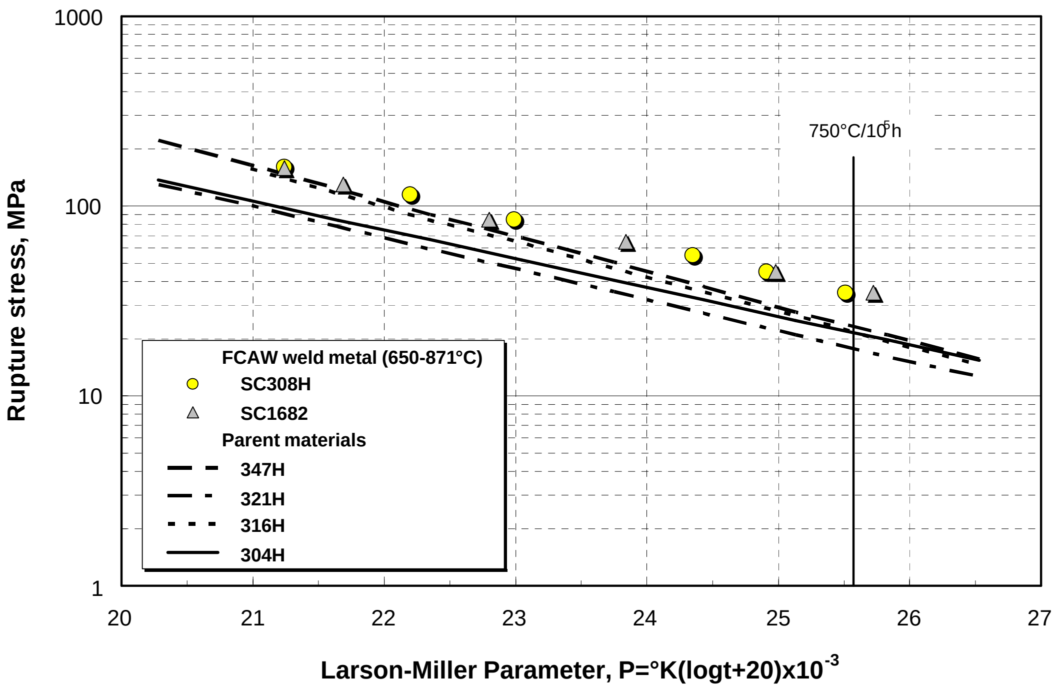


Figure 7: Larson Miller plot of stress-rupture data obtained for Supercore 308H and Supercore 16.8.2 FCW weld metal compared with minimum 10^5h rupture stress for relevant austenitic 3xxH parent materials (from ASTM DS 5S2)

It can be seen that the stress-rupture performance of the two weld metals is similar, and plot together as a single line with a slope very similar to the 304 base material but at higher stress. These trends suggest that there are no radical shifts or differences in the characteristics of microstructural evolution of parent and weld metals for the tested durations and temperatures.

With regard to rupture ductility as measured by reduction of area, the molybdenum-bearing Supercore 16.8.2 is generally superior to the Supercore 308H, Table 4. This is most apparent at the higher temperatures of 732°C (1350°F) and 816°C (1500°F), and after longer rupture times.

These creep rupture tests and other aspects of the use of 300H stainless steels at elevated temperature are discussed in more detail in reference [(5)].

7 Additional products

This document is primarily concerned with the use of 308H and 16.8.2 consumables in the manufacture and refurbishment of components fabricated from type 304H stainless steels. Other steels are used in cat crackers and dissimilar joints are required for transitions between CMn or CrMo steels and stainless steels, and for joining hexmetal and refractory anchor systems to various components.

Metrode offers a full range of welding consumables for all these applications, including the Nimrod range of nickel-based electrodes, other 300H stainless steels (eg. 347H) and CrMo consumables.

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APPENDIX 1

Fabrication & installation of an FCCU catalyst support air grid using 16-8-2 type stainless steel MMA electrodes and FCW

1 Introduction

In 1996, Esso Petroleum installed a new and very large type 304H stainless steel catalyst support air grid inside the lower section of the existing FCCU regenerator vessel at their Fawley Refinery (UK). This component is essential to the efficient regeneration of the catalyst and, hence, the economic performance of the whole unit.

Since this was a replacement item, to be installed during a major shutdown, time was a critical factor. Not only had the 14.3m (47.7ft) diameter grid to be fabricated to fit an existing vessel, and to very tight tolerances, including flatness, it had to be fabricated in the form of several sections which could be both transported to site and reassembled inside the vessel.

2 Choice of Welding Processes and Consumables

Historically, much of the welding (particularly site welding) of cat cracker/regenerator internals has been carried out using the manual metal arc (MMA) / shielded metal arc process (SMAW) with covered electrodes. Modern electrodes have been developed to give optimum compositions, good welder appeal and the ability to be used in a range of positions. In spite of these features, they are considered to have low efficiency in terms of both deposition rate and effective duty cycle. In order to improve manufacturing productivity at the pre-fabrication stage and, possibly more important, to reduce the total installation time on site, higher deposition rate semi-automatic gas shielded welding was considered essential.

Two options were available, namely MIG/GMAW solid wire or flux cored wire (FCAW). However, choice was dictated by availability, since the 'lean 16-8-2' weld metal exclusively specified by Exxon (USA) for 304H material, with Mo strictly controlled to 1.3%, was not readily available in the form of GMAW or FCAW wire.

Attention was therefore concentrated on the design and development of a suitable flux cored wire. It was envisaged that most of the welding would be carried out in the flat position, and since the optimum composition was more easily achieved with a 1.6mm (1/16in) diameter wire rather than a 1.2mm (0.047in), the 1.6mm (1/16in) wire became the preferred choice and was used wherever practicable.

Where it was not practicable or economic to use the flux cored wires, eg vertical welds or very short welds, MMA was used with electrodes designed to essentially the same composition specification. The electrodes were of the acid rutile (AR) type, AWS classified as E16.8.2–17, to give good positional performance in the smaller diameters, and excellent welder appeal and bead appearance with larger sizes in the downhand position. Although the electrodes had all the desirable features of the acid rutile types, the silicon level was deliberately controlled in the range 0.4-0.5% to minimise high temperature sigma formation and to maintain creep ductility. The various weld metal compositions and specification limits are summarised in Table 1.

Supermet 16.8.2 covered electrodes

	C	Mn	Si	S	P	Cr	Ni	Mo	Cu	FN*
Spec min	0.04	0.5	-	-	-	14.5	7.5	1.0	-	1
Max	0.08	2.5	0.60	0.03	0.03	16.5	9.5	1.3	0.75	6
Typical	0.05	1.0	0.4	0.01	0.02	15.5	8.5	1.2	0.1	3

Supercore 16.8.2 flux cored wire

	C	Mn	Si	S	P	Cr	Ni	Mo	Cu	FN*
Spec min	0.04	0.5	-	-	-	15.0	8.10	1.0	-	1
max	0.08	2.0	0.70	0.03	0.04	17.0	10.0	1.3	0.5	8
*Actual min **	0.052	1.34	0.29	0.012	0.030	16.2	9.4	1.20	0.15	3
*max **	0.056	1.40	0.31	0.17	0.032	16.6	9.6	1.26	0.18	4

* For batches used on the project

Table 1: Exxon specification limits and typical compositions for 'lean 16-8-2' SMAW and FCAW consumables

3 The Catalyst Support Grid (figures 1 & 2)

The grid consists of a flat disc, some 14.3m (47.7ft) in diameter, with a 1m (3.3ft) high skirt, via which it is welded to the regenerator vessel. The grid is stiffened with three concentric rings on the underside, and also has attachments for 34 adjustable supports which reach down to the base of the vessel. The grid has an array of precisely positioned holes for air distribution into the fluidised bed, and two large outlets for catalyst overflow.

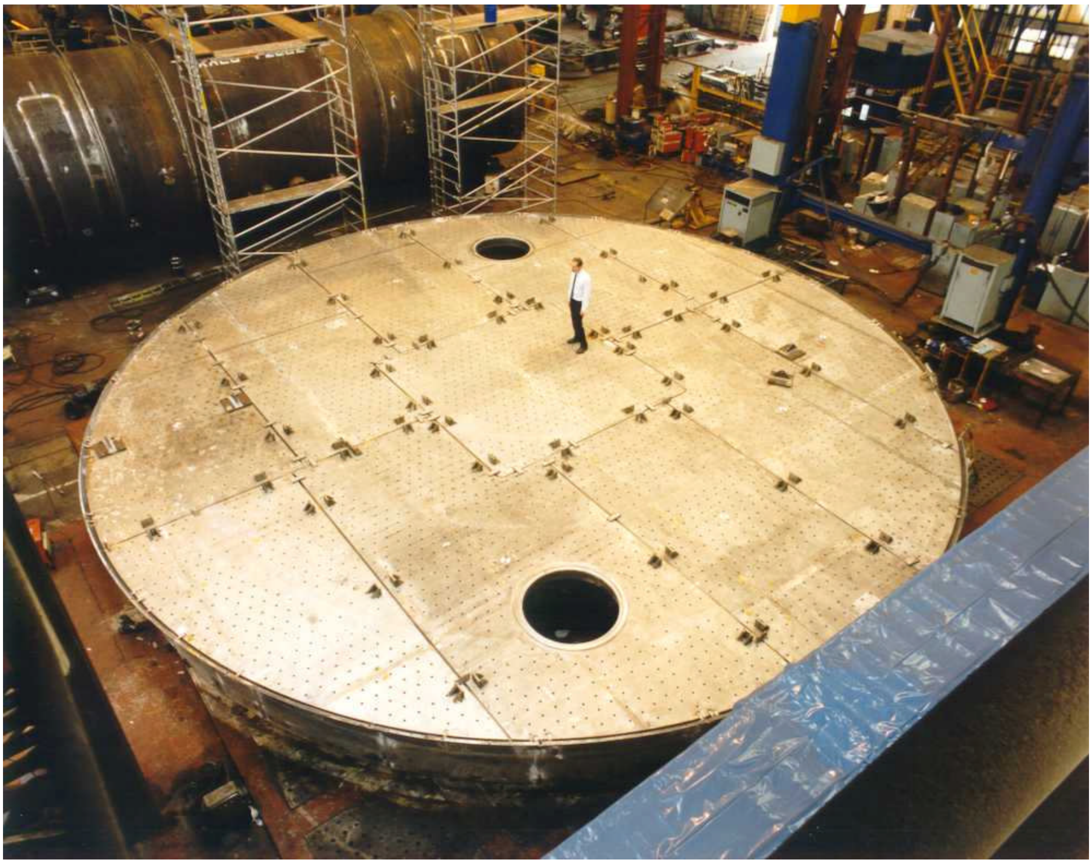


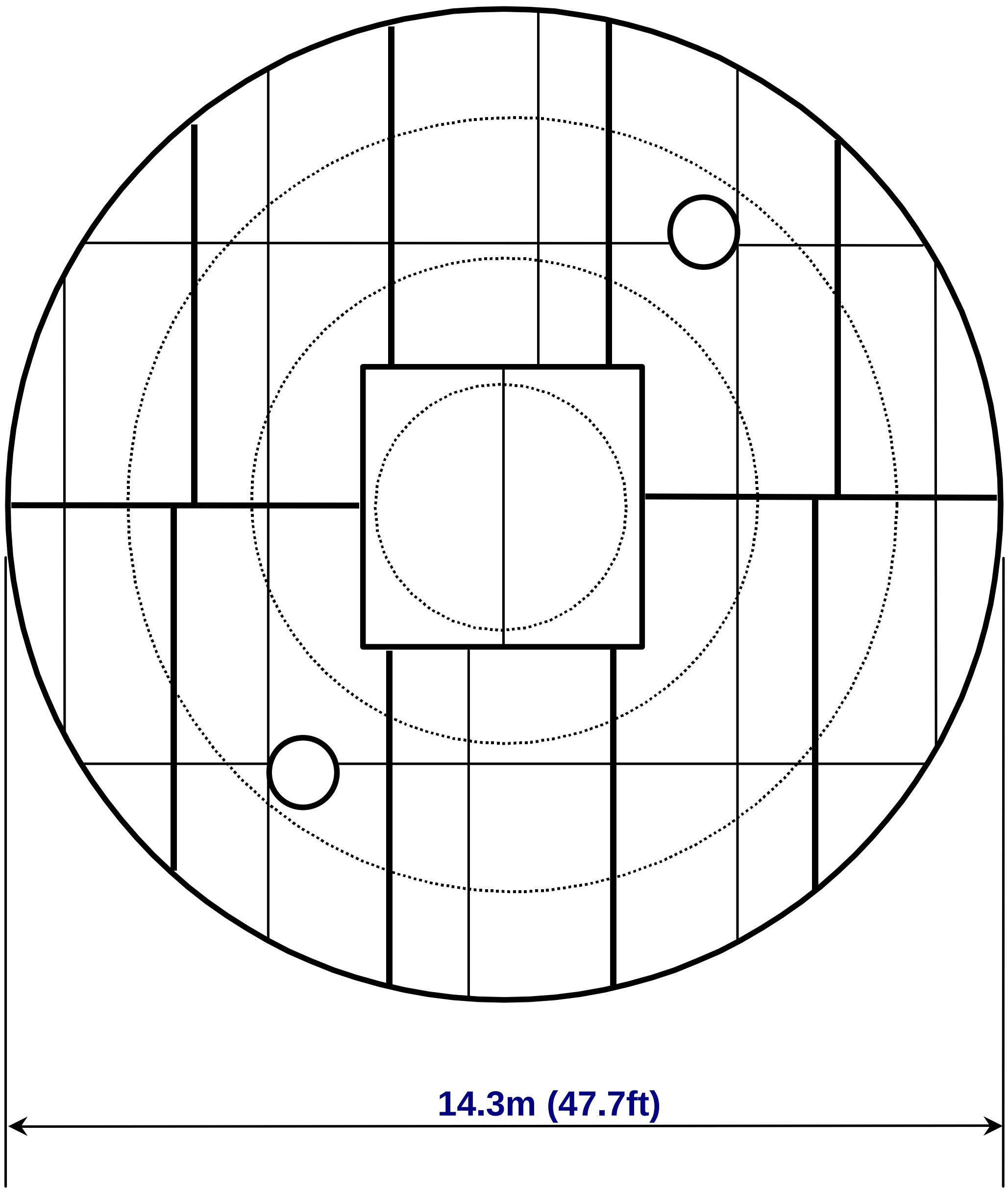
Figure 1: Catalyst support grid trial assembly in the fabrication shop showing section layout and welded joints to be completed on site.

The unusual aspects of the grid from a fabrication point of view were:

The skirt had to be manufactured to fit the existing vessel. This involved custom fabricating each section of the skirt to precise dimensions which had to be maintained after welding.

The sectioning of the grid into a number of individual sub-fabrications was dictated by the width of plate available, the maximum size for transportation to site, and the maximum size which could be lifted and handled within the vessel on site. The plate dimensions and section geometry meant that each section contained a number of butt welds between individual plates.

The grid, which was 38mm (1.5in) thick, had to be maintained flat to better than 3mm (0.12in) over any one section, and 6mm (0.25in) over any 10m (33.3ft) length. The requirements had to be achieved both during pre-fabrication and installation on site.



butt welds made between sections on site

butt welds made between individual plates at the shop prefabrication stage

positions of stiffening rings on underside

Figure 2: Plan view of catalyst support grid showing relative positions of shop welds, site welds and stiffening rings

4 Welding Procedures

4.1 Shop pre-fabrication

The welds critical to the shop pre-fabrications were:

- Butt welds between individual plates to make up the grid sections
- Butt welds between grid plates and the stiffening rings

The weld joint configurations employed are shown in Figures 3(a) and (b).

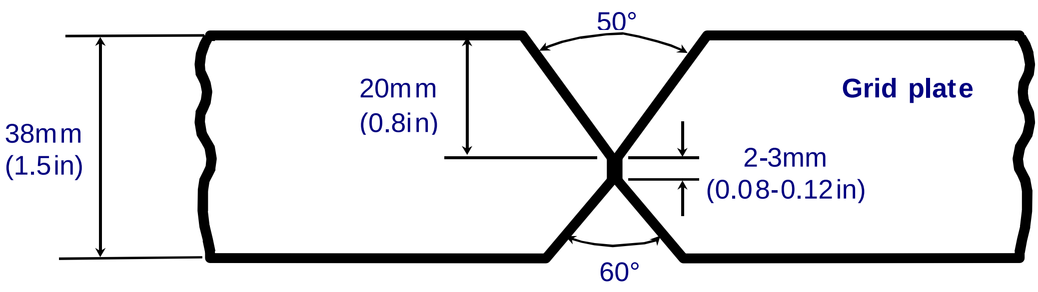


Figure 3a: Shop pre-fabricated butt welds in 38mm (1.5in) grid plate

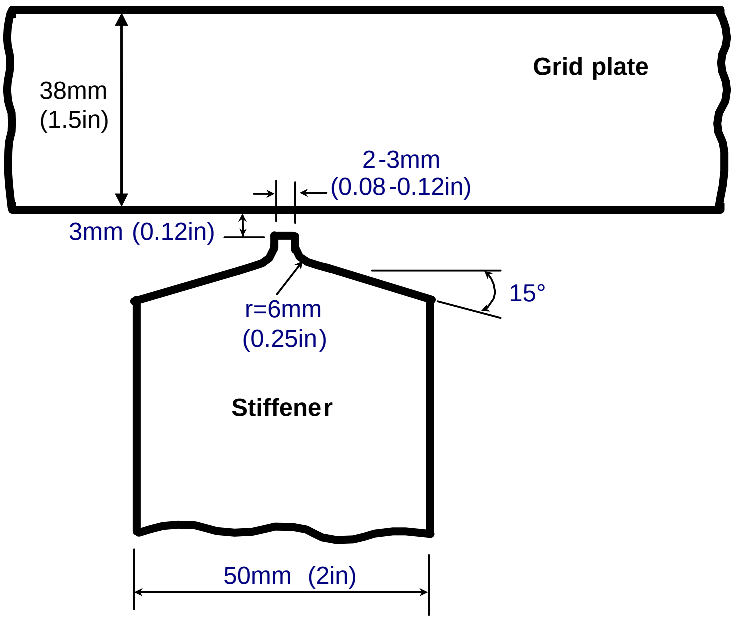


Figure 3b: Shop pre-fabricated butt welds between 38mm (1.5in) grid plate and 50mm (2in) thick stiffener

All the welds were planned as full penetration welds, and were designed to be welded in the flat position using the FCAW process. The wire used was **Supercore 16.8.2** 1.6mm (1/16in) diameter, with an Ar + 20%CO_2 shielding gas. A minimum of three runs of weld were completed on one side, and then arc air gouging was used to produce a sound root for the second side. No exact sequence of welding was followed, but welding was alternated to minimise distortion and maintain the flatness tolerance. In this respect, FCAW was found to result in fewer weld beads than SMAW used on previous projects which, in turn lead to significantly less distortion.

All the butt welds were subject to 100% radiography where practicable, and also to 100% dye penetrant inspection. No significant problems were encountered during the welding and the repair rate was minimal.

The complete grid was assembled in the shop with location lugs welded to facilitate accurate reassembly on site.

4.2 Site installation

The controlling factors on site were:

- A very limited 'time window' in which to install the grid, bearing in mind that numerous other aspects of refurbishment had to take place, including repair/replacement of other internals, eg cyclones and refractory lining
- The grid was positioned quite close to the base of the vessel which made welding on the underside extremely difficult. This, combined with the fact that welding in the overhead position results in low productivity, led to the decision to use single-sided welds onto a backing bar to join the grid sections. Positional welding was restricted to the joining of the stiffening rings and other minor attachments.

The weld joint detail for the site welds is shown in Figure 4. The integral backing bars were included as part of the shop fabrication and were used to support the individual sections as assembly progressed. The joint width was kept to a minimum consistent with good torch access and the need to achieve satisfactory penetration into the root area.

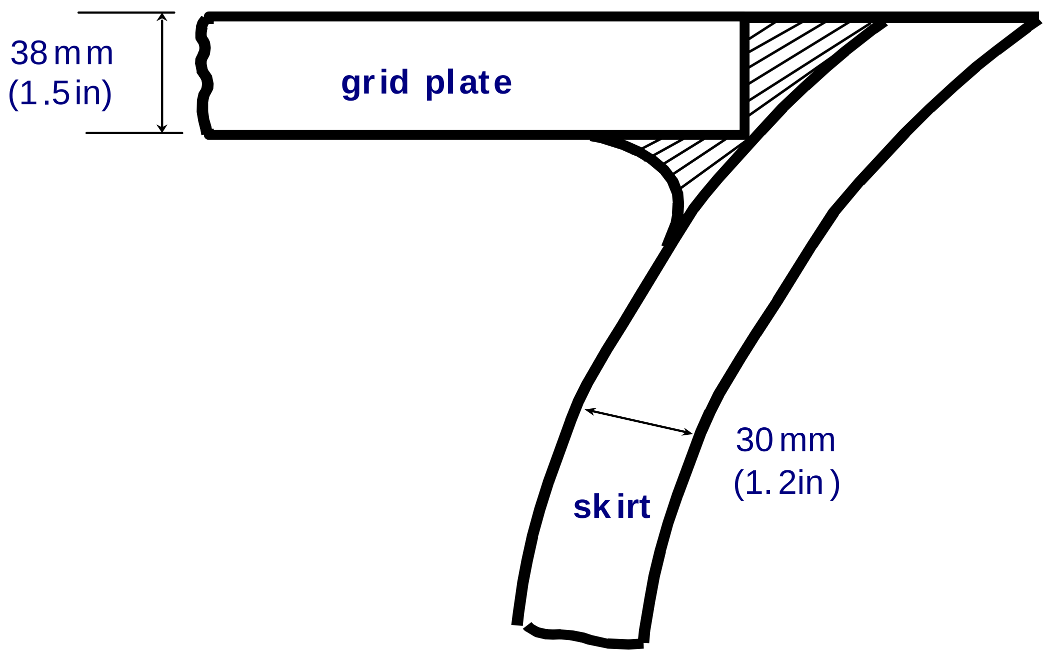


Figure 4a: Site butt weld between 38mm (1.5in) grid plate and 30mm (1.2in) thick skirt plates

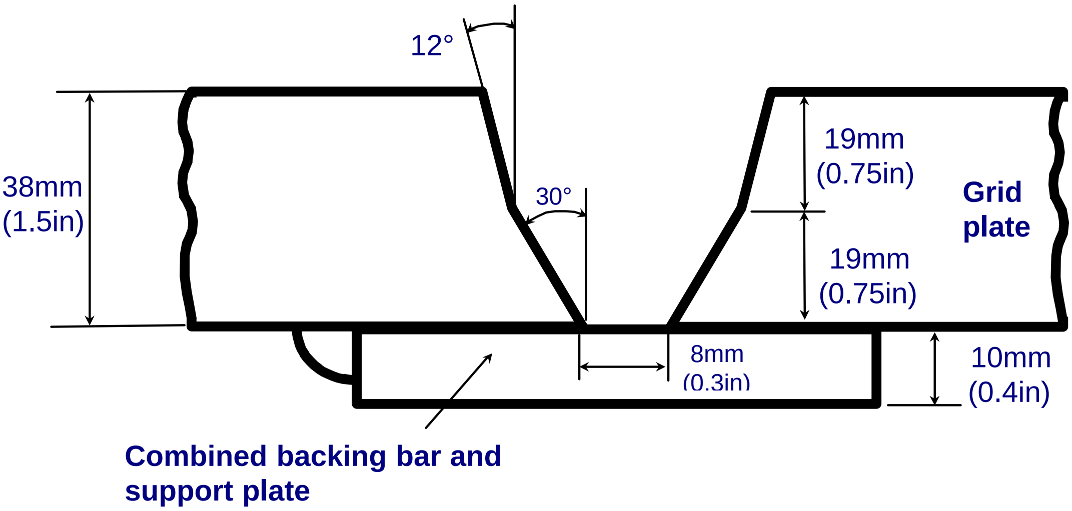


Figure 4b: Site butt welds in 38mm (1.5in) grid plate with access from the top side only

In theory the single-sided, unbalanced welds would have led to more distortion than the double-sided shop welds, but the effect was minimised by the presence of the ring stiffeners which were butt welded together before the main welds were completed. Butt welds in the stiffener rings were staggered to ensure that they did not coincide with the main butt welds in the grid. As in the case of the shop welds, FCAW was used wherever practicable, with **Supermet 16.8.2** MMA electrodes used for positional welds and short runs.

Once the sections were placed in position, they were welded together with block welds some 200mm (8in) long which fixed the dimensions of the grid as the work progressed. It was not practicable to assemble all the plates before welding commenced, so dimensions were monitored continuously to ensure that remaining sections would fit. Six welders were employed at any one time on the FCAW butt welding of the grid.

Flux cored wire welding at 250-280A in the downhand position generates a significant amount of welding fume, and in order to meet the allowable exposure limits, all those working in the vessel were equipped with filtered air supplies. Each welding station had local extraction and a bulk air flow was maintained within the vessel. However, air flow rates were controlled to avoid disruption of shielding gas.

In spite of the safety implications of site radiography, all site welds were subject to 100% radiography, together with surface dye penetrant testing. Installation of the support grid, together with all the other aspects of the refurbishment, was competed within the allowable shut-down period of 8 weeks. This was a remarkable achievement, since at any one time up to 50 men were working within the vessel. The benefits to the refinery of keeping within the timescale are self-evident when it is estimated that the losses incurred from a cat cracker shutdown can be up to £1m/day! ($1.6m/day).

5 Summary & Conclusions

The project described in this Appendix was completed in spring 1996, and the cat cracker in question was successfully put back into service with no reported problems. In all respects the project has to be considered a major achievement. The welding and fabrication aspects which led to this success can be summarised as follows:

- The careful planning which went into all aspects of the design and fabrication procedures for the support grid at both the shop fabrication and site installation stages.
- The extensive use made of the flux cored arc welding process to:
  - improve the deposition rate and productivity
  - reduce distortion and so achieve the very tight dimensional tolerance required
  - maintain a high level of structural integrity and minimise the defect rate.
- The use of suitable 16.8.2 type welding consumables designed to give
  - optimum welder appeal and productivity
  - maximum long-term high temperature creep rupture ductility combined with crack resistance

Since this time subsequent shutdowns have taken place which also made use of 16.8.2 consumables; including Supercore 16.8.2P positional flux cored wire. In the period since 1995, use of FCAW has grown for the fabrication of original equipment and replacement items for cat crackers. Types 16.8.2 and 308H consumables are readily available as flux cored wires, and are in regular use worldwide, helping to improve efficiency, productivity and reduce downtime in critical refinery plant.

Acknowledgements

Metrode is grateful to staff at Derby Specialist Fabrications, Derby, UK for information about shop fabrication of the grid and for permission to use Figure 1.