Welding Problems in Chemical Plant Manufacture —Case Studies

By S. R. RAMCHANDRAN*

Introduction

In the manufacture of equipment for fertilizer and chemical plants, a number of different materials are used for corrosion resistant services, high temperature services, low temperature services etc. The Planning and Development Division of the Fertilizer Corporation of India, as designers over the last few years have come across quite a few problems in the welding and fabrication of some equipment. The present paper reviews some of the more baffling problems encountered, and is intended to provoke thought and discussion among the different parties involved : viz. the designers, welding technologists, vessel manufacturers, welding and consumable and equipment manufacturers. It require the co-ordinated efforts of all these interests to tackle these problems successfully. In the Indian context, particularly, there is greater need to carry out research and testing work to establish satisfactory data on the effects of various welding parameters—material compositions, filler metal composition, electrode coverings, welding techniques, preheat and post-weld heat treatment etc.

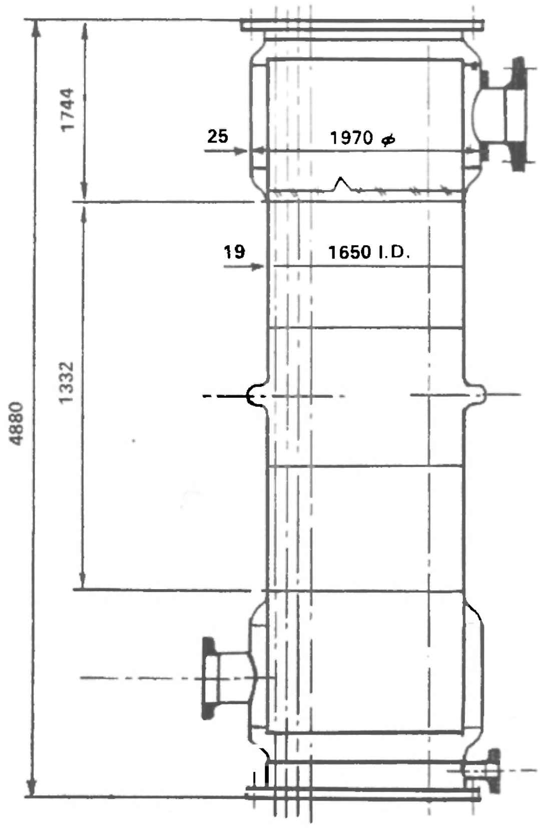
The problems dealt with in this paper may be grouped under the following classes :—

(1) Welding of austenitic stainless steels.

(2) Welding of Cr.-Mo steels.

(3) Stainless steel weld overlay cladding

(4) Welding of C & C-Mn Steel for Low Temperature service.



Ftg. 1. Solution Reboiler

* Mr. Ramchandran is with the Planning & Development Division of Fertilizer Corporation of India Ltd,, Sindri. This paper was presented at a meeting of the Institute held in Calcutta.

(1) Welding of Austenitic Stainless Steels

Serious problems arose in the welding of a shell and tube exchanger constructed of stainless steel type 347 (Nb stabilised) by a leading manufacturer. (See Fig. 1).

Welding of shell was completed as per qualified procedure using type 347 covered electrodes. All weld seams were 100% radiographed and inside surface of seams Dye Penetrant checked. No defects were observed. At this stage no Dye Penetrant check was carried out on outside surface of welds. Subsequently after partial assembly of tubes, during which the exchanger was supported on 2 sets of rollers near the middle, with the larger diameter ends and tube plates overhanging, Dye Penetrant check was carried out on outside surface of weld seams as required by specification. A number of cracks were observed chiefly on the circumferential seams, C-7 & C-10 and some on long seams (See Fig. 2). All cracks were longitudinal and were observed in the weld metal and at the toes of the weld. On grinding and Dye Penetrant check these were found to be 5-6 mm deep. On removal of reinforcement rings at the cone-cylinder junctions cracks were observed in the parent metal at the attachment of the stiffening rings. The tubes were removed and the vapour jackets cut for access to inside. On Dye Penetrant check inside, extensive cracking was observed on circumferential seams C7, C8 & C9 at fusion line.

Seam C9, the worst affected was chipped out over full width of weld to a depth of 8 mm, dye-checked for complete removal of cracks and welded with type 316L electrodes, both indigenous and imported. The

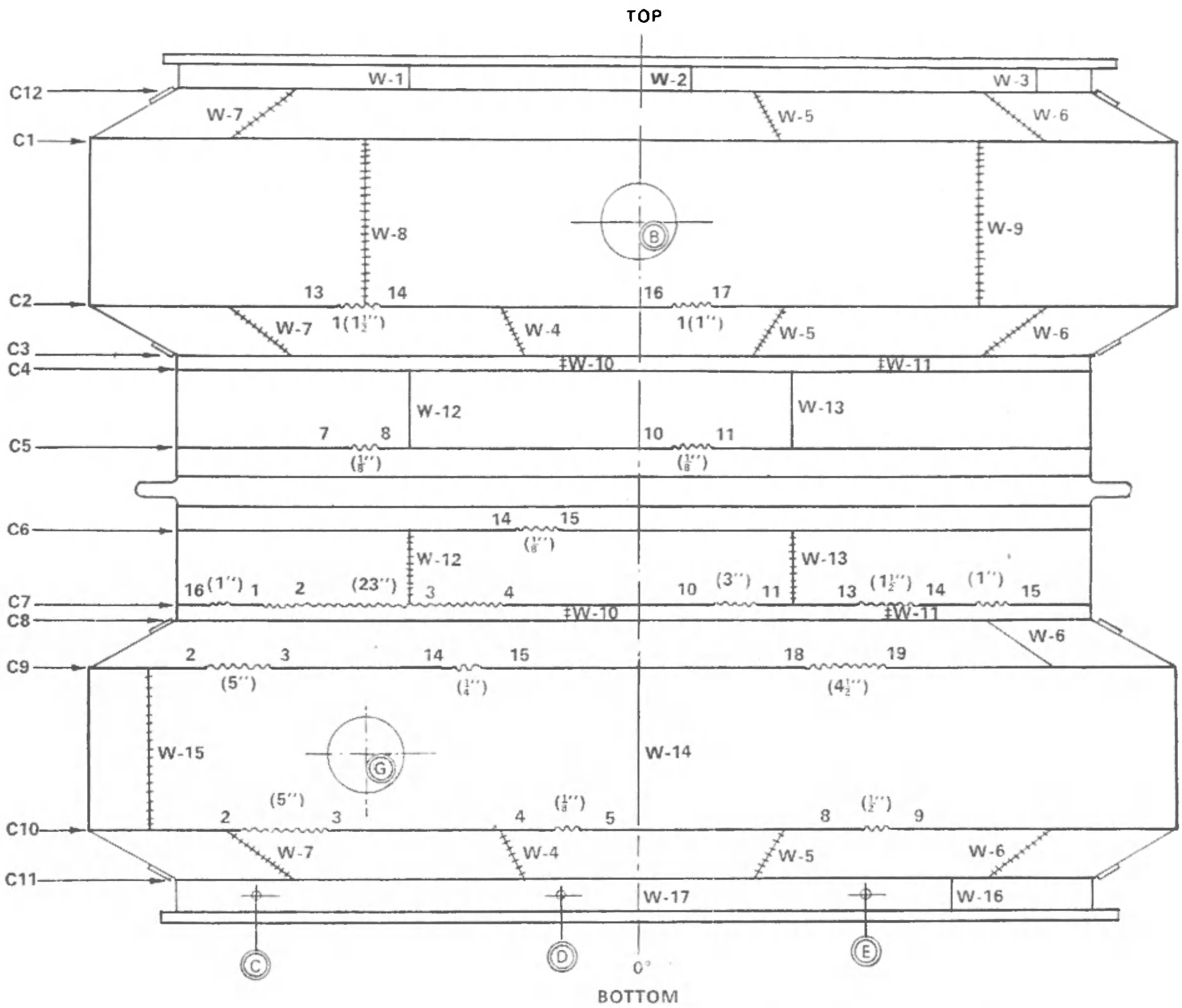


Fig. 2. Developed Layout of weld joints on Solution Reboiler showing cracks on outside surface.

cracking persisted after repair. Subsequently all 316L deposit was chipped out and rewelding carried out with imported 347 electrodes. By this time, the cracking problem got completely out of hand and the repairs were given up. The shell was cut into 5 segments by cutting seams C5, C10, C11, C12.

Two segments of shell were annealed in furnace at 1025°C in order to soften the material and remove effects of all previous working and enable rewelding. (For one segment consisting of cone it was decided to make a new conical reducer).

When the above difficulties were encountered, procedure tests were carried out to observe the hot-cracking tendencies of different electrodes. Tests were carried out on same parent material of same thickness, using types 347 and 316L electrodes. Both produced welds free from cracks. In a restraint test, 316L gave crack-free deposit while type 347 showed cracks. Manufacturer's analysis of batches used were checked and observed to be within specification limits (See Table 1).

The above problem points to the special care necessary in selection and testing of electrodes. It has been felt that the lack of consistency in quality of electrodes has been one of the main causes of cracking. In such cases, filler metal composition may have to be controlled to closer limits and careful welding techniques established-straight head deposition, keeping heat input low etc. The normal requirements of electrode specifications are inadequate for selection of electrodes for the welding of such difficult steels and qualification tests on each batch of electrodes including restraint tests may be necessary before using each batch. It also points to the need for more careful examinations of weld surface for cracks and fissures, not detectable by radiography alone.

Another welding problem encountered in welding of stainless steel type 316 was rejection of welds due to "segregation". This has occurred in a number of cases and has been rather baffling. The indication on the radiograp his a sort of "graininess" or "snow flake" appearance. Welds showing such indications were rejected by

TABLE—I

Chemical Analysis of Plates (%)

	(1)	(2)	(3)
Cr.	17.55	17.28	17.62
Ni.	10.92	10.22	9.24
C	0.06	0.055	0.06
Si	0.48	0.38	—
Mn.	1.59	1.42	—
P	0.024	0.038	—
S	0.012	0.011	—
Nb	0.64	0.57	0.70

Chemical Analysis of Electrodes (Deposited weld metal) used :

	Batch No.	*C* (%)	*Cr* (%)	*Ni* (%)	*Mn* (%)	*Nb* (%)	*Mo* (%)
Electrode 1	070	0.07	18.05	9.35	0.90	1.07	—
	035	0.09	18.16	10.53	1.35	1.06	—
	075	0.07	18.03	10.93	0.87	1.20	—
Electrode 2	592	0.07	18.81	8.75	1.29	0.98	(Fe : 6.6%)
	276	0.06	18.66	9.42	1.18	0.90	(Fe : 6.5%)
Electrode 3	121	0.055	17.77	11.4	1.35	0.92	2.4 (Fe : 6%)
Electrode 4	01607	0.024	19.4	12.1	1.49	—	2.59 (S-0.008 P-0.007)
Electrode 5		0.035	18.28	9.79	—	—	2.64
		0.033	18.3	10.35	—	—	2.34

the inspector and repairs and rewelding was called for. In some cases, on repair and rewelding, similar indication appeared. A sample from one such weld was cut and both transverse and longitudinal sections were polished and etched and examined under a magnification of 500 x. No evidence of segregation or fissures or other abnomality of structure was found. The Inspector however felt that this kind of indication represents flakes or fine fissures and weakens the weld.

(2) **Welding of Cr-Mo Steels**

Here the main problem is concerning post-weld heat-treatment. In one high pressure heater, the channel side has a hemispherical end welded on to the tube plate, both made of 1Cr-½Mo steel. The tube-plate thickness is 300 mm and the thickness of end is 65 mm. Tubes are of S.S. 347 attached by welding to a 5 mm S.S. weld overlay on the tube-sheet. (See Fig. 3).

The problem concerns the post-weld treatment of the closure weld of end to tube sheet. Stress relieving of entire vessel with tube bundle may damage the S.S. overlay cladding and tube-tube sheet joint. Local stress relieving will not effectively relieve stresses because of the restraint provided by the tube sheet which will be cold. Because of this restraint, free expansion of the weld and adjacent area is prevented and on cooling, residual stresses will be introduced at the junction with tube-sheet, which is undesirable.

The question arises whether post-weld treatment is always necessary for Cr-Mo Steels. All the pressure vessel codes and boiler regulations call for stress-relieving. Now, the primary purpose of the treatment is preventing a hard brittle micro-temperature in the HAZ, which is undesirable and may be dangerous from the point of view of fracture. If this can be achieved by using a sufficiently high preheat of say 250°C and limiting the maximum hardness of the weld and HAZ to a value of VPN 260 or so, is the post-weld treatment really necessary—especially, in cases like the above where it might result in damage. The ASA Code for pressure piping, for instance, does not specify post-weld treatment of Cr-Mo steel as a mandatory requirement. The requirement is confined to specifying the maximum hardness of weld and HAZ for the different material groups.

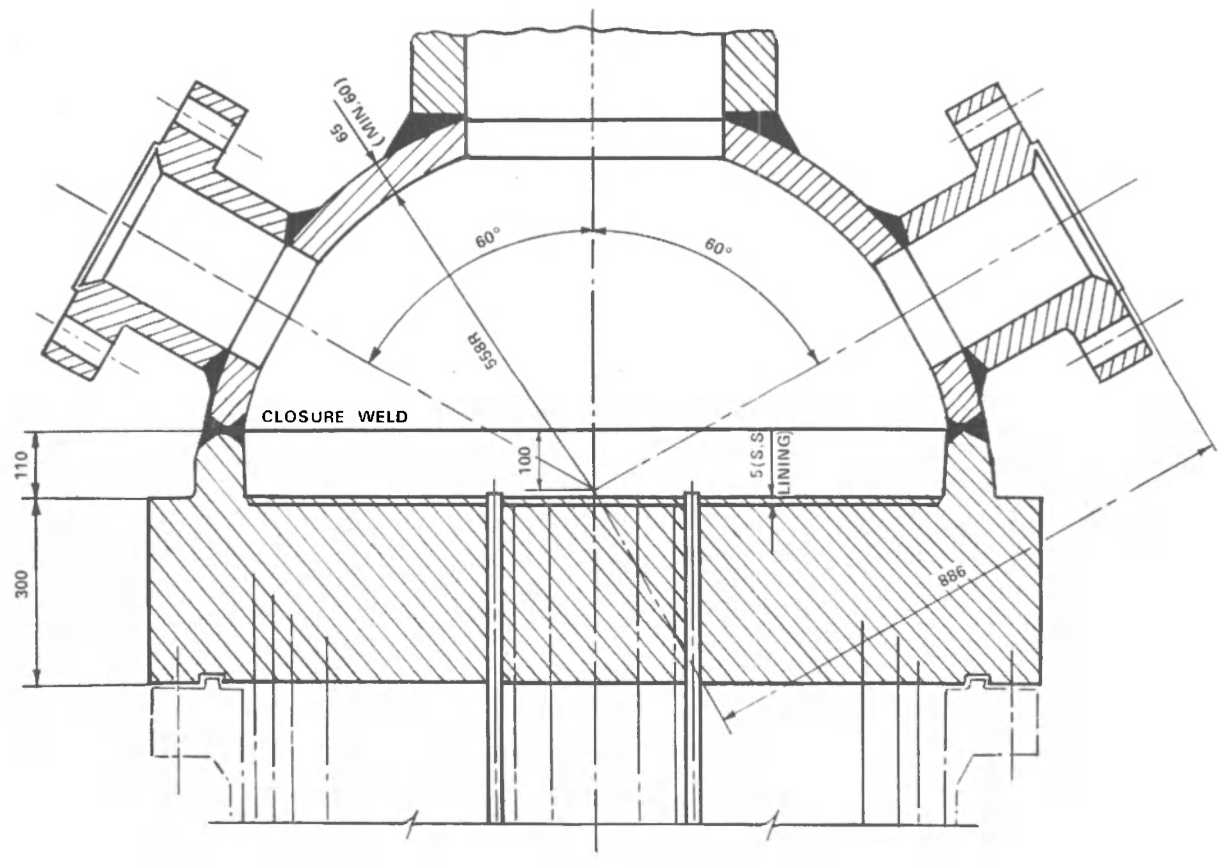


Fig. 3

Another question arises in the tube-tube sheet welding of Cr-Mo steel. In the case of fixed tube sheet exchangers, stress-relieving of completed exchanger with tubes welded at both sides involves the risk of damaging tube joints as a result of unequal expansion. Other methods involve stress-relieving after the tubes are welded to one tube sheet only followed by welding of tubes on the other side and again stress-relieving by introducing the exchanger partially into the furnace. This suffers from the disadvantage of extra time and expense and the risk of scaling of the tube holes and tube surfaces at the free end which might impair expansion and/or welding. The use of a high enough preheat subject to limiting maximum hardness of weld and HAZ offers a satisfactory solution. Tests have been carried successfully on plain butt-welds in 8 mm thick. 1Cr-½ Mo steel using preheat of 250°C only with no post-weld treatment. It has been possible to obtain hardness in the weld and HAZ less than 250 VPN.

(3) **Stainless Steel Weld Overlay Cladding**

In a heat exchanger, the tube plate material is 1Cr ½ Mo steel 300 mm thick and tubes are of S.S. type 347. The attachment of tubes to tube sheet is by welding and for this purpose 5 mm S.S. overlay cladding is specified on the tube sheet surface on channel side. Overlay cladding was done in 2 layers, first with 310 filler metal followed by second layer of 347. The overlay welding was done without adequate preheat. On completion, the overlay surface was machined and dye-checked. A number of fine cracks and porosity were indicated. Even after grinding out and re-welding, these indications continued to appear at different places. Eventually the whole overlay and a part of base metal were machined off and on dye-check, there was evidence of numerous fine scattered cracks. Similar cracks and defects also occurred in overlays over plain C.S. carried out by an overlay machine using MIG process. This has been a very baffling problem and it has not been possible to identify the cause of such cracks, which occurred in overlays of 347 and 316L composition. In one case, where the overlay was on a cover, it was possible to modify the design and apply sheet lining. But, since there are many applications of such weld overlay cladding in fertilizer and chemical plant equipment, satisfactory methods and equipment have to be devised to carry out such overlays successfully. This is a case where the electrode and welding equipment manufacturers may be able to offer a solution.

(4) **Welding of C & C-Mn Steels for Low Temperature Services**

There are many applications in the fertilizer and chemical plants of C and C-Mn steels used for Low Temperature service down to about -30°C and even to -50°C. In most of these applications, the base material quality is of Low Temperature with certified impact properties at the lowest operating temperature. In some cases, at temperatures upto-10°C ordinary carbon steel of boiler quality is also used. In our specifications for such equipment, min. impact requirements on charpy V specimens are specified for weld metal as well as HAZ. But, in many cases, with the notch in the HAZ, it has been difficult to meet specified requirements. The problem has been particularly acute with ordinary carbon steel of boiler quality like IS : 2002 Gr.2A. The impact values of HAZ are particularly influenced by welding techniques, electrode size, heat input, type of electrode, use of preheat and post-weld treatment etc. In many cases like large storage tanks or spheres, post-weld treatment is not possible, and preheating can be very expensive.

Impact tests at -10°C have been carried out on welded IS : 2002 Gr.2A plates, 25 mm thick. Welding was carried out with low hydrogen electrodes using 3.2 and 4 mm electrodes, without preheat and with preheat of 100°C. In practically all cases, while the weld metal gave satisfactory impact values (about 35 ft-lbs), the HAZ specimens gave low values <(15 ft-lb, the min. specified). One interesting observation during these tests was that the parent plate values varied widely from as low as 12/15 ft-lbs to about 50 ft-lbs at -10°C. This is probably accounted for by variation in heats, effects of segregation etc.

In another case, a C-Mn steel (20 M5 with 0.1% V) was welded and impact tests carried out on weld metal and HAZ specimens. The test plate thickness was 40 mm and welding was carried out using E 7018 electrodes of 10 SWG throughout (103 runs) ; preheating was done to 175°C and post-weld stress-relieving at 625-650°C for 2 hours.

Results :	*HAZ*	*Weld (1)*	*(2)*
	0.6 kg-m	1.75 kg-m	13.25 kg-m
	0.5 "	3.35 "	13.45 "
	1.35 "	3.25 "	7.15 "

The parent material was impact tested at the mill at -33°C and as per mill test certificate has satisfactory impact values (6-7 kg-m).

Here the problem is apparently due to unsatisfactory welding technique or choice of electrode. (Use of 10 SWG electrodes throughout results in too low a heat input ; higher sizes 4 & 5 mm would be preferable). The effects of V are also unknown. It may be partially responsible for the embrittlement. The problem in the above cases is establishing satisfactory welding procedure to obtain good fracture-toughness of weld and HAZ.

Another interesting problem arose in the welded construction of a vessel in Low Temperature steel (BS : 1501- Gr.32A, LT33). The formed end of the vessel (20 mm thick) is made in a number of steps.

(1) Dishing by hot pressing in 2 segments.

(2) Welding

(3) Further hot forming completed in 3 stages with intermediate heating between stages.

Tests were carried out on test plates subjected to the above treatment and finally stress relieved at 600°C (as required for completed vessel). 3 different electrodes were tried. In all cases, there was a significant drop in UTS from the original value of 56 kg/mm² to about 47 kg/mm² in the welded specimen after treatment. All other properties like YP, elongation and Charpy-V energy at -33°C were satisfactory. In all these cases, the fracture was in the welds and the parent plate when tested after the same treatment indicated only a drop to about 50.6 kg/mm². Since the design is based on the min. properties as per specification, this presents a problem.

The thermal treatment consisted of

(1) Heating to 1030°C

(2) Heating to 900°C after welding—1st stage

(3) Reheating to 900°C after partial forming

(4) Reheating to 900°C

(5) Heating to 1030°C for final forming

} 30-45 min. soak each time.

The problem here is rather unusual and arises from the repeated thermal cycling necessitated by the manufacturing method. All the same, such situations do arise in manufacture in this country and the factors responsible for the fall in strength have to be identified and controlled to establish acceptable procedures.

Conclusion

The problems discussed above are actual case studies and are indicative of the types of problems encountered in the fabrication of vessels and exchangers for the process industries. The solutions may not be simple and can be established only by the combined efforts of designers, welding engineers, electrode manufacturers and metallurgists through careful analysis and application of tests. The paper would accomplish its objective, if it serves to provoke thought and stimulate research into the problems by vessel manufacturers and electrode manufacturers and others concerned with welding.