Reformer Tube and Weld Inspection, Replacement, and Repair

Dye penetrant testing and gamma-radiography proved the two most useful non-destructive testing techniques for assessing the condition of the welds of a primary reformer.

A.J.P. Tucker
African Explosives and Chemical Industries Ltd.
Johannesburg, South Africa

AE & CI operates a 600 ton/day steam reforming ammonia plant at Umbogintwini, about 10 miles south of Durban, Natal, South Africa. The feedstock is refinery off-gas, naphtha or any given mixture of both. The primary reformer is of Kellogg design, top fired with John Zink burners, operating at a nominal pressure of 500 lb./sq. in. gauge.

The plant was put on line in October 1967. There was an emergency shutdown in November 1967, when a weld in a riser tube developed a serious leak. Extensive cracking was found in riser tube welds, and all the risers were replaced with new material. Since then, the reformer has run without major mishaps, although extensive weld repairs have been necessary at intervals. This article describes the action taken in November 1967 and subsequent major repairs in March 1970 and March 1971. Methods of inspection of tubes and welds, and of repairs done, are detailed and commented upon.

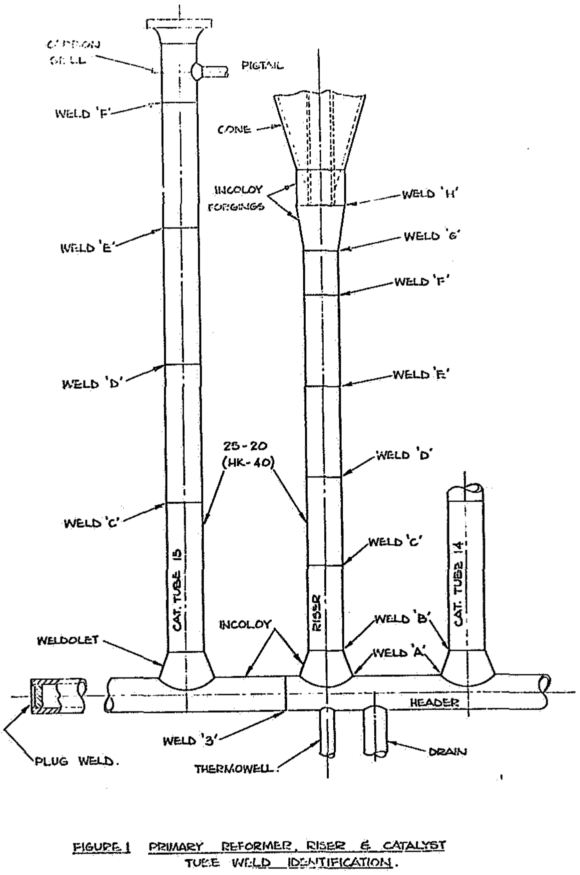

Figure 1. Primary Reformer, riser, and catalyst tube weld identification.

There are 140 catalyst tubes, arranged in five vertical banks of 28 tubes each, connected by weldolets to five internal headers. Five internal risers, each one situated centrally in a header, and also connected to the header by a weldolet, lead to a refractory lined and water jacketed external transfer line passing across the top of the primary reformer furnace to the secondary reformer.

The catalyst tubes hang freely in the furnace space, being supported in pairs from trunnions, on springs situated above the furnace. The transfer line is also supported on springs. The catalyst tubes are 4 in. bore, 0.88 in. minimum wall thickness, centrifugally cast HK-40 material. The headers are of Incoloy 800. The weld layout in the headers, catalyst tubes and riser tubes is shown in Figure 1. The original method of fabrication of the welds in the fired zone was as follows:

Header butt welds	T.I.G. Inconel 82 root run; Inconel 182 metal arc weld out.
Catalyst tube welds A and B	T.I.G. Inconel 82 root run; Inconel 182 metal arc weld out.
Catalyst tube welds D and E	T.I.G. low carbon 310 root run; high carbon Type 310 metal arc weld out.
Riser welds A, B and G	T.I.G. Inconel 82 root run; Inconel 182 metal arc weld out.
Riser welds C, D, E and F	T.I.G. low carbon Type 310 root run run; high carbon Type 310 metal arc weld out.

Weld failure - 1967

Riser welds – On November 17, 1967, after the plant had been on line only a few weeks, it had to be shut down when a serious leak was observed in a riser tube in the primary reformer. Examination of all the riser welds by externally applied dye penetrant showed:

1. All the G welds were cracked, two of them very

seriously. The cracks were circumferential, running around the outer edge of the welds. The cracks in the two seriously cracked welds penetrated through to the root, running down the interface between weld and parent tube.

2. About half of the HK-40 to HK-40 welds in the risers contained minor to serious circumferential cracks, mainly on the center line of each weld.

It was decided to cut out all the riser tubes and install a new set. Our original intention had been to remove each riser in one piece for subsequent detailed examination of the welds. However, a long jib crane needed for this operation was not immediately available. The night shift, working with a spirit of emergency, decided to do the job without a crane by cutting each riser into smaller pieces, hauling each piece out separately. The removal was successfully and expeditiously done but, unfortunately, each cut was made by grinding through each weld. Thus, all evidence of the nature of the cracks was destroyed. Sufficient weld metal remained, however, to show that there was no metallurgical reason for the failures. The weld metal was identified and found to comply with specification. There was no indication of long term creep deterioration, although there was evidence that the G welds had been done twice. The G welds were examined with special care as there had been reports of earlier failure of these welds owing to the use of incorrect welding rods.

Catalyst tube welds – All the catalyst tube welds were examined by externally applied dye penetrant. Minor circumferential cracking was found in several. These cracks were removed by careful grinding which, in all cases but five, did not reduce the wall thickness below the specified minimum, as the cracking was confined to weld reinforcement. In the five cases where grinding was fairly deep the butt welds were heat treated locally, and then repaired using high carbon Type 310 metal arc welding electrodes.

One short longitudinal crack was found adjacent to a weld. It was decided to remove this weld by cutting through the tube 6 in. each side of it. The two cut ends were then locally heat treated and a spool piece of new HK-40 was welded in.

All new HK-40 to HK-40 welds in catalyst tubes and risers were made by T.I.G. Inconel 82 root welding, and high carbon Type 310 metal arc weld out.

Examination of the cut out catalyst tube showed no positive reason for the longitudinal crack. This crack, which was about 1/2 in. long and 1/8 in. deep, showed clearly on dye check but was so fine that it was difficult to detect under a microscope even when its location was known. It is considered possible that it was an original shrinkage crack not noticed on initial inspection

Heat treatment – Before repairing the catalyst tubes and installing the new risers, welders had to be trained and approved. It was decided to use the cut out riser tubing for training and test pieces. However, difficulties immediately arose, as we could not make sound welds on the used tube. It was possible to make sound T.I.G. root welds, and even start the metal arc weld out successfully, but sooner or later, delayed root cracking would occur. This started at one side of the root bead and progressed in the heat affected zone adjacent to the weld out.

On advice from, and with assistance of, colleagues from Imperial Chemical Industries Ltd., we decided to heat treat all used HK-40 tubing before attempting any welding. The heat treatment temperature range was considered to be extremely critical; it had to be sufficiently high to dissolve carbides precipitated in service, but not high enough to cause liquation. The difference between these temperatures is small, the optimum temperature for carbide solution being about 1,250°C, with liquation starting at 1,300°C. The range decided upon was 1,225- to 1,275°C held for 1 hr., followed by rapid cooling to prevent re-precipitation of carbides. Local hardness tests were done after heat treatment, and a hardness of less than 200 V.P.N. was considered satisfactory. The treatment proved successful in that we were, at that time, able to make crack-free welds on used material.

The method of heat treatment was to warp Cooper resistance heating Kanthal finger elements around the tube and insulate with two 1 in. layers of Kaowool ceramic blanket insulation held on with Type 310 wire. Power was supplied from welding machines (a.c. or d.c. controlled by a walkie-talkie radio link.

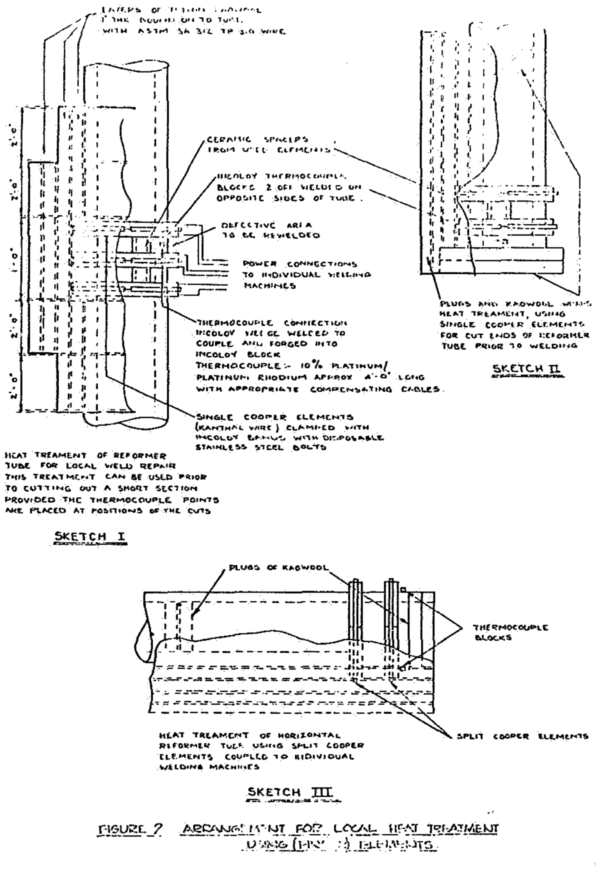

Figure 2. Arrangement for local heat treatment using finger elements.

The procedure is illustrated in Figure 2. However, experience on tubes which have been in service longer than those treated in 1967 has shown that successful results are not then certain. Another warning to be sounded is that the temperature required is at the limit for the Kanthal elements, which become embrittled. It is not advisable to attempt two high temperature heat treatments with the same set of elements as a failure of the elements part way through the treatment is possible, and then the treatment has to be started all over again. Since the warming-up period can be several hours, this can be a very time consuming process. It is, however, possible to re-use the elements for lower temperature work (e.g., stress relief at 650°C) if they are handled carefully.

No metallurgical reasons for the weld failures were discovered. They were all considered to be caused by extraneous mechanical forces other than normal working loads. Evidence for the extraneous forces was:

1. The two most seriously cracked risers were found, on cutting through the welds, to be under severe compression.
2. The top half of some risers was streaked with a calcareous deposit, indicating that water from the jacket of the transfer line had overflowed down the risers. Such an overflow would certainly introduce thermal shock and thermal stress.
3. The transfer line had bowed up at a point one third of the way from its free end towards the secondary reformer.
4. The bottom headers were all noticeably distorted in an irregular manner.
5. The springs supporting the catalyst tubes and transfer line were found to be incorrectly calibrated, so that the rows of catalyst tubes were incorrectly balanced.

The steps taken to eliminate or reduce the chances of extraneous stresses were described in a paper *(1)* presented by Heinz at the 1968 Tripartite Conference in Montreal, so we will not discuss them here. Suffice it to say that we have experienced no failures similar to those of 1967 since that date.

Weld failures — 1970

A shutdown of the plant, after a continuous run of some ten months, and a total on heat load time of 18,500 hr. was planned to commence on February 11, 1970. In fact, the shutdown commenced on February 3, when a leak was observed, apparently coming from the bottom of a catalyst tube in the primary reformer. Removal of the lagging at this point showed that the leak was actually through a badly cracked butt weld in the Incoloy 800 bottom header. This weld had been made with Inconel 182 weld metal. Subsequent examination showed that a large number of other Inconel 182 welds was cracked, some of them very seriously. A thorough examination of all welds in the primary reformer revealed cracks near several catalyst tube welds and in one butt weld in a riser. One catalyst tube and one riser were cut out and replaced and repairs were done to approximately 150 welds.

Details of the examination and repair methods are given below:

Header butt welds – Inspection of the header butt weld, the failure of which had caused the premature shutdown, showed that it had split through the top half. The weld, a side construction weld, was sent for metallurgical examination. All the other header butt welds were then examined as thoroughly as possible by all means available and applicable viz:

1. Visual
2. Dye penetrant
3. Ultrasonic
4. Gamma-ray
5. Destructive metallurgical examination.

Dye penetrant checks showed that one other butt weld, also a site weld, was seriously cracked, this time around the bottom half. This weld was also cut out for metallurgical examination. Dye checks did not show any more cracked welds.

Following the dye check, all the header butt welds were carefully examined by gamma radiography. As we did not know how any possible cracks might be disposed, it was decided not to rely only on radiographs taken normal to the weld, but also to take shorts from 60° each side of the normal, and from four clock positions around the weld. Thus, 12 radiographs were taken of each weld.

None of the radiographs showed conclusive evidence of cracking, although some did give evidence of weld defects. Those welds which showed the most positive evidence of defects were cut out and metallurgically examined. This examination revealed that:

1. The two welds which were obviously cracked had failed by multiple creep fissuring which appeared to start in the body of the weld and proceed towards the bore and the o.d., Figure 3. The leaker had fissured right through, the final failure being through to the bore. The second weld which had cracked but not leaked, was fissured all through except the T.I.G. root run (in Inconel 82).
2. None of the welds cut out after gamma radiography was found to contain serious fissures. There was, however, clear evidence of grain boundary creep deterioration as shown in Figure 4.

To maintain the correct longitudinal dimensions of the headers after repair, it was necessary to insert a spool piece at each place where a butt weld had been cut out. In removing a butt weld about 1-1/2 in. were lost. To avoid having two butt welds very close together, it was decided to cut additional material from the headers at the site of each cut, to allow the insertion of a 4 in. spool piece. Weld repairs were done in exactly the same way as the original weld viz: T.I.G. Inconel 82 root, Inconel 182 metal arc weld out. No heat treatment was necessary and no difficulties were met when effecting the repairs.

Other Inconel 182 welds – The condition of the header butt welds made us very suspicious of all other welds in the furnace containing Inconel 182 weld metal. These existed

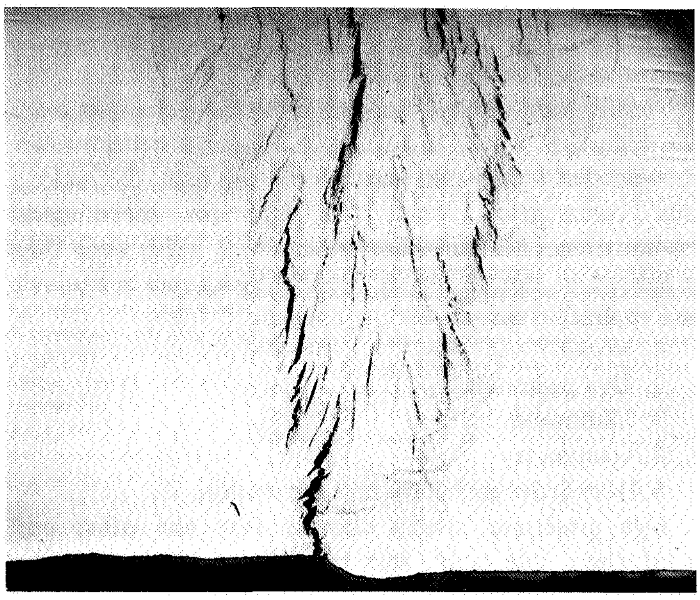

Figure 3. Section through cracked Inconel 182 weld, bottom header. This appeared as an isolated crack before sectioning (mag. 3x).

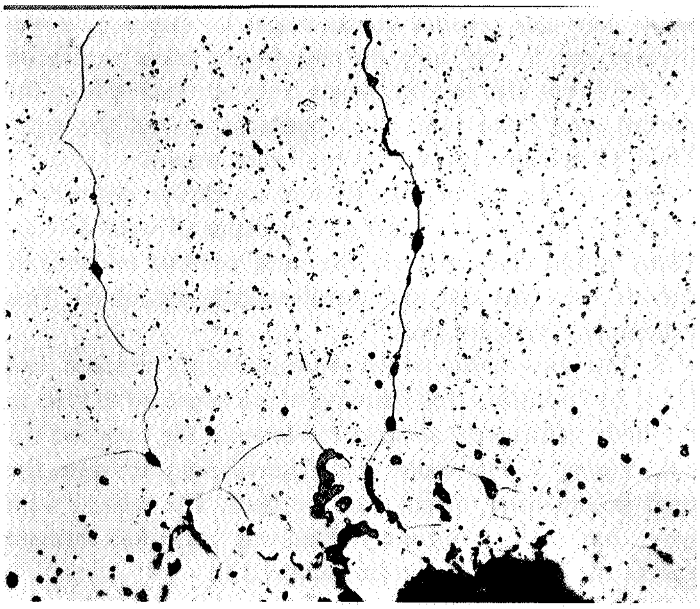

Figure 4. Creep damage in otherwise uncracked Inconel 182 weld (mag. 200x).

at the following points:

1. At the transition between the riser and the transfer line (Weld G - 5 welds)'
2. At the weld between each riser and catalyst tube and the header weldolet (Weld B - 145 welds).
3. At the weld between each weldolet and the headers (Weld A - 145 welds).
4. At the end plugs of each header (10 welds).

With the exception of the riser welds (weld G) none of these welds was, at the time, considered accessible for satisfactory radiographic examination. Ultrasonic examination did not give clear results and inspection was largely confined to dye checks. At first, this was confined to surface dye checking only.

Surface dye checking immediately revealed extensive cracking in all the A welds on the risers and a large number of A welds on the catalyst tubes. On two riser welds this cracking was almost completely through, being deepest at the flank position. On learning from the header butt weld examination that the cracking there appeared to originate in the body of the weld rather than at the surface or the bore, ten apparently uncracked A welds on catalyst tubes were carefully ground at the flank positions and dye checked again. Multiple branching cracking was revealed which, on further grinding and intermediate dye checking, was found to persist to a depth of about 3/8 in. It was decided at this stage to grind all the remaining A welds to a depth of 3/8 in. without intermediate dye checking on the assumption that all were likely to contain cracks. Subsequent dye checking showed that all the welds except five were now free of cracks. On these five further grinding had to be done to a depth of 5/8 in. No cracks were found in any of the B or G welds.

Weld A on riser E had to be ground right through to the bore. Weld A on riser A had to completely removed because the riser had been cut out at this point, another weld (weld E) in the riser having been found to be cracked. These welds were remade with T.I.G. Inconel 82 root and Inconel 182 metal arc weld out. The majority of the other welds were patched with Inconel 182 electrodes, although a few were repaired with Inco A electrodes. No difficulties were experienced in effecting repairs; all repaired welds were ground and, on dye checking, found to be free of cracks.

Catalyst and riser tube welds – Closed circuit T.V. equipment was available for the planned shutdown. It had been intended to examine internally as many catalyst and riser tubes as possible in the time available, but owing to the pressure of repair work, only those tubes which had been running hot prior to the shutdown were examined. No indication of defects was obtained. The nature of the other defects found suggests that T.V. inspection of tube bores has little value, unless the tubing should be stricken with massive bore oxidation.

Every catalyst and riser tube was examined visually on the outside, and every weld zone was examine externally by dye check. Five cracks were found in catalyst tubes in areas near, but not in, welds. Four of these cracks were ground out by very light grinding, without materially affecting the wall thickness. The fifth crack (in tube A9, just above weld D) was first observed as running circumferentially, parallel with the weld. When lightly ground, this crack proved to continue beneath the surface and, at each end of the observed circumferential crack, it swung round to run in a longitudinal direction. It was decided to remove this tube completely, by cutting at weld B, and to replace it with a new one.

On the risers one weld (weld E, riser A) showed clear signs of cracking. Two cracks were found, diametrically oppositie one another in the center of the weld reinforcement, each about 2 in. long. The appearance was of a branching nature, suggesting creep failure. It was decided to remove this riser, by cutting through at weld B, and replacing it with a new one. It should be noted that the cracks in this weld, although subsequently found to be about 1/3 in. deep, could not be detected by gamma radiography. The two tubes removed were sectioned and samples sent for metallurgical examination.

The curved pattern of the crack found above weld D in catalyst tube A9 suggested thermal shock rather than progressive failure by creep or other gradual deterioration under normal operating stresses. However, in the region of the crack there was severe bore porosity and oxidation which reduced the effective sound wall thickness to 0.62 in. (specified minimum 0.88 in.). Typical bore deterioration is shown in Figure 5.

The well developed centre line cracks in weld E of riser A penetrated to a considerable depth leaving, at one position measured, a residual wall thickness of 0.66 in. The etched appearance of the weld deposit showed a paucity of carbides but, except in the vicinity of the major surface crack, there was no evidence of intergranular deterioration or abnormal structural change. The typical microstructure is shown in Figure 6. Analysis of the weld deposit indicated a carbon content of only 0.26%, with chromium and nickel in the expected range. The cracking was considered to be due to an inadequate carbon content producing a mechanically weak weld which developed a crack under longitudinal stressing conditions. For a longitudinal stress

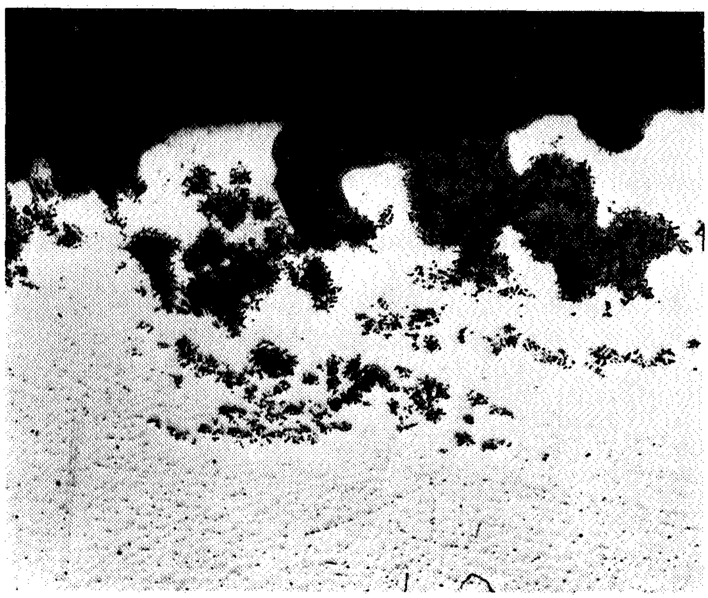

Figure 5. Deterioration of bore of HK-40 tubing (mag. 6x).

Table 1

Summary of reformer tube examination, February 1970.

Items Examined	Number in Furnace	Method of Examination	Results
Header butt welds*	20	Radiography, dye penetrant, ultrasonics, metallography	② seriously cracked; all show signs of metallurgical deterioration (multiple micro cracks). micro cracks).
Header butt plug welds*	10	Dye penetrant	No defects found
Header/riser weldolet welds*	5	Dye penetrant, metallography, ultrasonic	All found to contain severe multiple fissures two right through.
Header/catalyst tube* weldolet welds	140	Dye penetrant, metallography, ultrasonics	All found to contain multiple fissures to a depth of about 5/8 in. Metallurgical deterioration.
Weldolet/riser and catalyst tube welds*	145	Dye penetrant, gamma radiography, C.C.T.V., metallography	No obvious defects seen. Metallurgical deterioration.
Riser/transfer line welds*	5	Dye penetrant	No defects found
Catalyst tube butt welds	420	Dye penetrant, C.C.T.V.	Surface cracks found near, but not in,⑤ welds. Four cracks removed by light grinding. One catalyst tube removed.
Riser butt welds	20	Dye penetrant, radiography	Circumferential cracks found in ① weld by dye penetrant (not shown on radiography).
Catalyst tubes	1 (④ lengths of tubing) removed	Dye penetrant, metallography Dye penetrant, metallography	Severe bore oxidation, some longitudinal cracks. Effective sound wall reduced to 0.6 in. in placed (0.88 in. required).

Notes:
1. All items marked * are Inconel 182 welds. Other welds are 25 Cr/20 Ni/0.4C.
2. Catalyst tubing is HK-40 (25 Cr/20 Ni/0.4C).

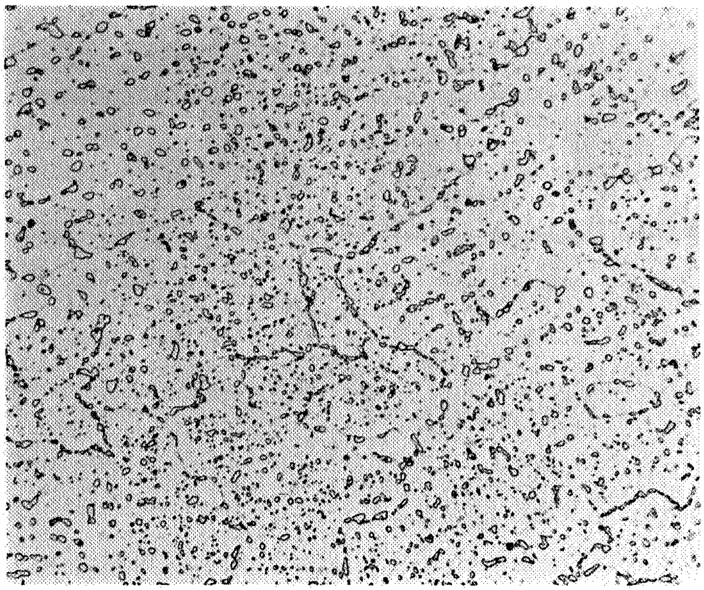

Figure 6. General microstructure of cracked Type 310 weld in HK-40 catalyst tube. (mag. 400x).

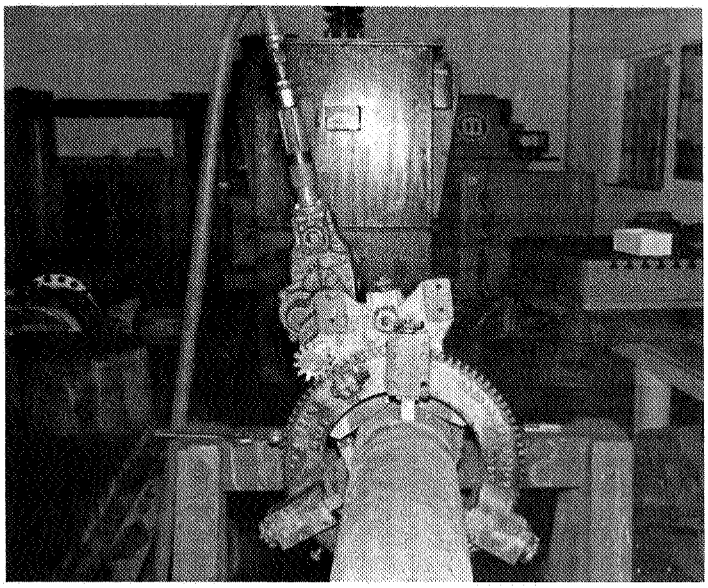

Figure 7. Pass cutter in position on tube.

to be present, the riser must have been in tension; when the tube was cut, the two halves sprang apart about 1/2 in.

The main conclusion we drew from the results of our 1970 examination was that Inconel 182 metal arc weld deposits are not suitable for our reformer furnace duty. This conclusion is obvious from the text and his highlighted by Table 1 which summarises the inspection methods and results. Out of 153 defective areas found, 147 were in Inconel 182 weld metal. Of the remaining six defective areas, four proved to be very minor and only one HK-40 to HK-40 weld was seriously cracked.

Removal and replacement of tubes

In 1967, when HK-40 weld failures were discovered, repairs were made in situ, after applying the heat treatment described earlier. On later occasions this procedure was abandoned for two reasons. First, the heat treatment took a long time and, second, we had doubts about the effectivess of the heat treatment on material which had been in service for more than a few hundred hours. On the other hand, we had more than enough evidence that it was possible to produce sound repair welds on Incoloy 800 and on welds made with Inconel 182, even when they had been in service for several thousand hours. A decision was made, prior to the 1970 shutdown, that no attempts would be made to effect in situ repairs on HK-40 tubing, or on HK-40 welds in catalyst tubes. Instead, if significant defects were found in HK-40 tubing, we decided to remove the complete tube by cutting through at weld B, and install a complete new tube. This decision was encouraged by our acquisition of a cutting machine which enabled us to make this cut neatly and rapidly. The cutting machine, known as the pass cutter, is a portable device which is clamped on to the pipe. It has three adjustable cutting heads mounted on a split ring which encircles the tube. As the ring is rotated by compressed air power, the cutters are advanced automatically on each rotation. The machine is illustrated in Figure 7.

After cutting, a straight bevel preparation is ground on the weldolet and everything is ready for installation of a new tube-already end prepared. The time taken to remove a tube and install a new one is detailed in Table 2.

Failure — 1971

In March 1971 the ammonia plant was shut down after a heat load time of 26,800 hr. On this occasion the shutdown took place as planned, and the inspection of the reformer furnace was well organized in advance.

Based on previous experience, we adhered to the following inspection procedures:

1. Dye penetrant – surface checks of all welds, preceded by surface grinding on randomly selected A and B welds.
2. Visual inspection – visual internal inspection of all E welds in catalyst tubes.
3. Radiography – random radiography of selected B welds.

Table 2

Time necessary to remove and old tube and install a new one.

	Operation	Time Taken
1.	Assemble cutter on tube	42 min.
2.	Cut tube	30 min.
3.	Remove tube	25 min.
4.	Grind preparation on weldolet	2 hr. 30 min.
5.	Position new tube	25 min.
6.	Line up tube to weldolet, tape and argon purge	1 hr.
7.	Weld butt complete (one welder on T.I.G. root run and two welders on weld out)	9 hr.
8.	Grind completed weld surface	1 hr. 30 min.
9.	Examine weld – dye check	20 min.
10.	Radiograph and view results	1 hr. 30 min.

The decision to visual inspect all catalyst tube E welds was made because, during 1970, we had received reports that several operators had reported root cracking in the top HK-40 to HK-40 welds in the fired zone (viz., our E welds). The results of these inspections are detailed below.

Dye penetrant examination – All the bottom header butt welds were examined with dye penetrant; no defects were observed.

All catalyst tube welds A, B, C, D, and E were examined. Surface cracking was found in 17 of the A welds, all of which had been repaired the previous year. Major cracking was found in 4 B welds, none of which had been found to be defective in 1970. All these welds contained Inconel 182 weld metal.

All riser welds were examined and branching circumferential cracking was found near the center line in weld F on two. These welds were made with high carbon Type 310 weld out.

Visual inspection of E welds in catalyst tubes – Visual inspection was done by telescopic viewer which consisted of three basic parts, as shown in Figure 8.

1. A glass mirror, inclined at 45^{o} supported in a sheet steel frame, illuminated by a 12 V quartz-iodine lamp. The frame was attached by threaded joints to 3/4 in. dia. electrical conduit, which could be extended by threaded ferrule connectors to other conduit lengths to reach the weld to be examined. Electrical connection to a 12 V car battery was made by rubber covered twin flex taped to the lowest length of conduit only and stretched taut above this.
2. A spigotted wooden centreing disc, positioned on the top flange of the catalyst tube, slotted so that the conduit could be easily adjusted up or down, yet still held in close contact with the tube wall, and drilled so that the telescope could be located above the centre of the visible portion of the illuminating mirror.
3. A Dumpy level type telescope, focusing from 5 ft. to infinity.

It was decided to use this equipment for visual inspection of the root of E welds, rather than closed ciruit T.V., for two reasons, First, it would be free from electrical interference and, second, it was considered that it gave clearer viewing.

The equipment was used to view all the welds on all the catalyst tubes. From this inspection some 20 welds were considered suspect, but only one was suspected of containing a serious defect. This weld was subsequently radiographed.

Radiography – All the bottom header butt welds were radiographed; no defects were observed.

A high proportion of the B welds was radiographed; defects were noted in some of thse, but only in welds in which cracking had already been revealed by dye penetrant examination.

As a result of the visual inspection it was decided to radiograph the E weld considered suspicious from visual inspection. The radiographs revealed serious root cracking. It was then decided to radiograph all the E welds in the catalyst tubes. Root cracking, varying from minor to severe, was found in 56 of these welds, in 15 of which the cracking was judged to be severe. There was little correlation, however, between the results of visual and radiographic inspection.

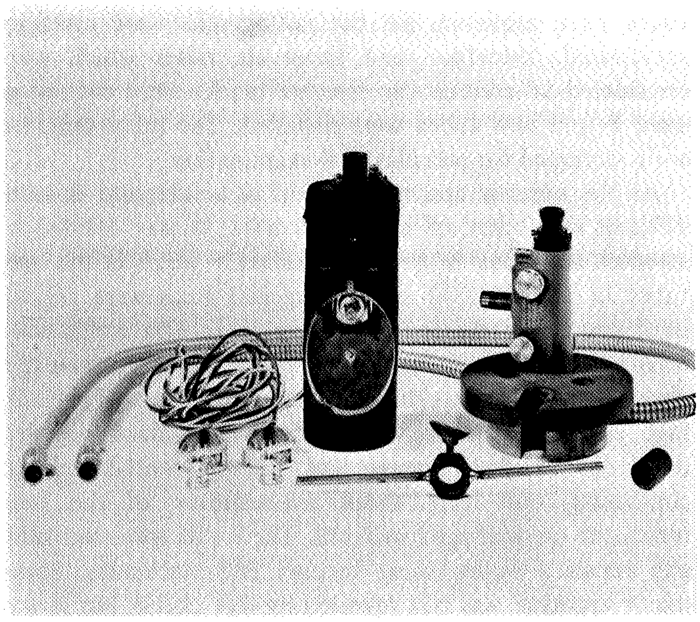

Figure 8. Apparatus for internal visual examination of E welds.

All the welds E, F, G and H in the risers were radiographed; no defects were observed except for root cracking, considered to be minor, in two of the E welds.

Repairs – The repairs to the Inconel 182 catalyst tube welds found to be cracked (A and B welds) were done in exactly the same way as in 1970, i.e., by grinding out all cracked areas and then patching, with Inconel 182 electrodes.

Concerning the 56 cracked E welds (all HK-40 to HK-40) we did not have facilities for heat treating 56 welds prior to repairing, nor did we have 56 replacement tubes; only 6

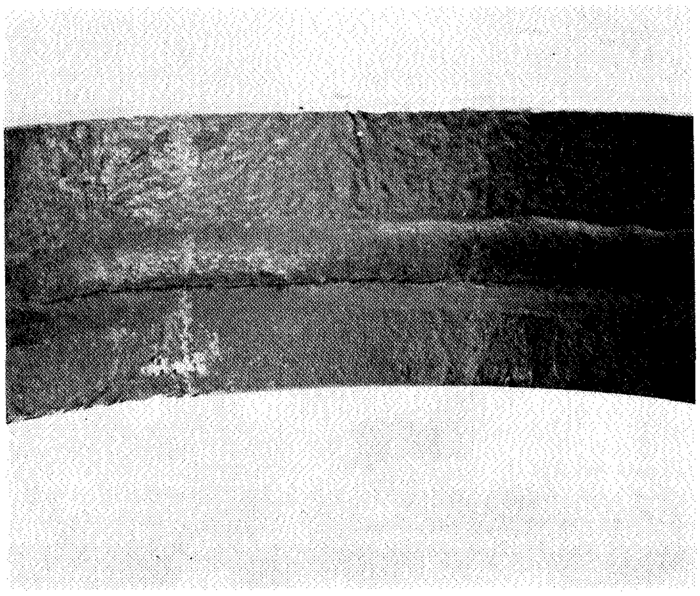

Figure 9. View of bore on typical E weld.

tubes were available. All the radiographs were carefully scrutinized, therefore, and those six tubes which were considered to contain the severest cracks were cut out at weld B and new tubes were installed. The tubes removed were sectioned for metallurgical examination.

As the removal and replacement of a riser tube is more difficult than that of a catalyst tube, it was decided to attempt the repair of the two cracked F welds in the riser tubes in situ. First of all, the cracked areas were ground until dye check showed they were clear. The welds were then heat treated in the manner described earlier and dye checked again. The welds were then patched with Type 310 high carbon electrodes. Subsequent dye check revealed numerous small transverse and circumferential defects, confirming our fears about the efficacy of the heat treatment on well-aged material. The welds were reground and repaired again, using Inconel 182 electrodes. Some minor cracking was still revealed by dye check, but it was decided not to persist with attempts to produce perfect repairs as welds with worse defects were, perforce, being allowed to remain elsewhere in the furnace. Similarly, no attempt was made to repair the two E welds showing minor root cracking.

Examination of catalyst tube E welds – Visual examination of the E welds, after they had been removed from the furnace, showed why visual examination with the telescopic viewer had not been informative. Figure 9 is a view onto a ring cut from a tube, and shows the root of a weld. Very little information can be obtained from this. Figure 10 is a view of the same ring, but showing the end sections. There can be no argument about the extent of the cracking.

A sample of one of the most severely cracked welds showed, Figure 11, that the cracking originated at the junction between the weld root and tube material. It moved, after some interruption, into the body of the root run and thence into the weld out, without significant deviation from the horizontal (radial) plane. Figure 12, from another position in the same weld, at the position of worst alignment, shows how the crack starts at an off-set in the root run and proceeds inwards without suppression or elaboration.

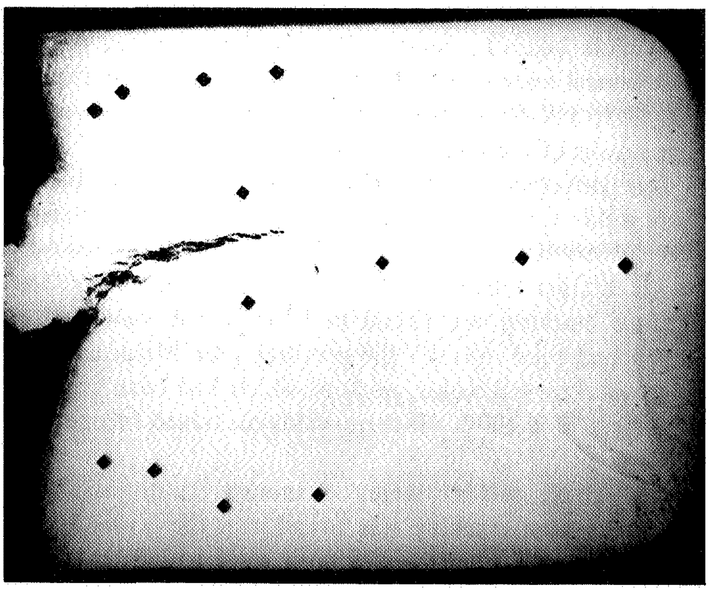
Figure 11. Root cracking in E weld (mag. 3x).

Figure 13, shows a macrophotograph of the weld, which from radiography, appeared to be the worst cracked. It will be seen that the full extent of the cracking extends with much side-stepping through 60- to 70% of the weld thickness. The microstructure of this weld showed grain boundary creep deterioration, as shown in Figure 14.

The fact that the cracks observed took a preferential path through the weld metal rather than the cast tube can be attributed to the fact that the weld metal has inherently inferior high temperature strength properties than the tube. It is considered that the cause of the fissuring must be high temperature creep, induced by thermal gradiants and

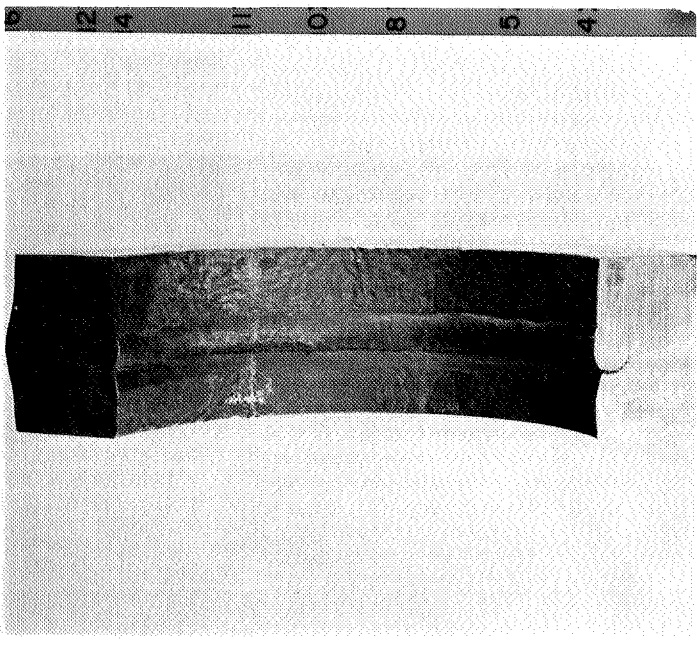
Figure 10. View of sectioned E weld.

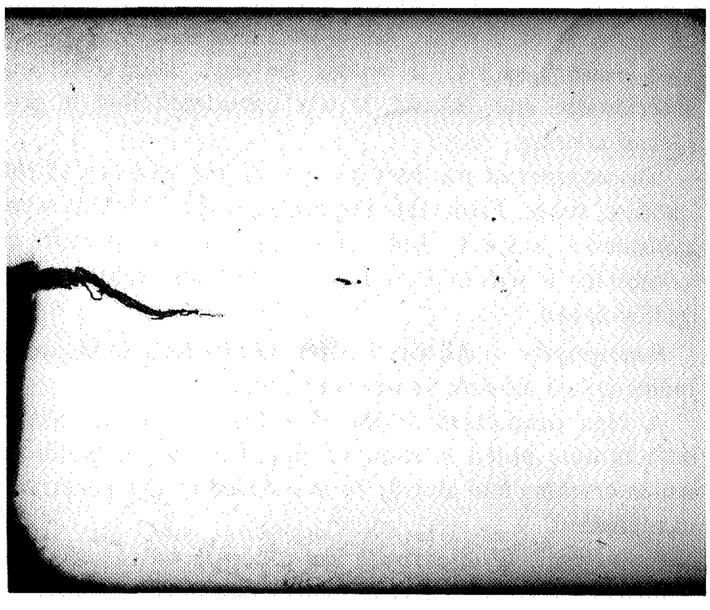
Figure 12. Effect of tube off-set on location of root crack (mag. 3x).

stresses which exist very largely during unsteady conditions, e.g., during startup and shutdown. The location of the fissuring is induced by stress concentrations produced by the weld bead profile.

With the exceptions of the troubles which occurred in 1967, the causes of which were probably mechanical owing to faulty assembly of the tubes, AE & CI has encountered a number of weld failures, and discovered a large number of weld defects, which can be expected to become progressively worse. The critical areas have been:

1. Al weld containing Inconel 182 metal arc weld deposits.
2. The top HK-40 to HK-40 welds in the fired zone of the furnace (weld E). These welds were made with a low carbon Type 310 root run and high carbon Type 310 weld out.

It was considered, after the 1970 shutdown, that deficiencies in the then installed tubes and, principally, deficiencies in the welds, warranted the procurement of a complete new tube assembly. For this new assembly all welds made previously by Inconel 182 weld out have been made completely by T.I.G. Inconel 182 welding. The HK-40 to HK-40 welds, previously made with Type 310 high carbon electrodes, have been made by automatic T.I.G. welding using filler wire of almost exactly the same composition as the parent tube. The new assembly has not yet been installed, but plans are ready for its immediate installation should there be another major breakdown on the present furnace.

Figure 13. Deep crack in E weld (mag. 3x).

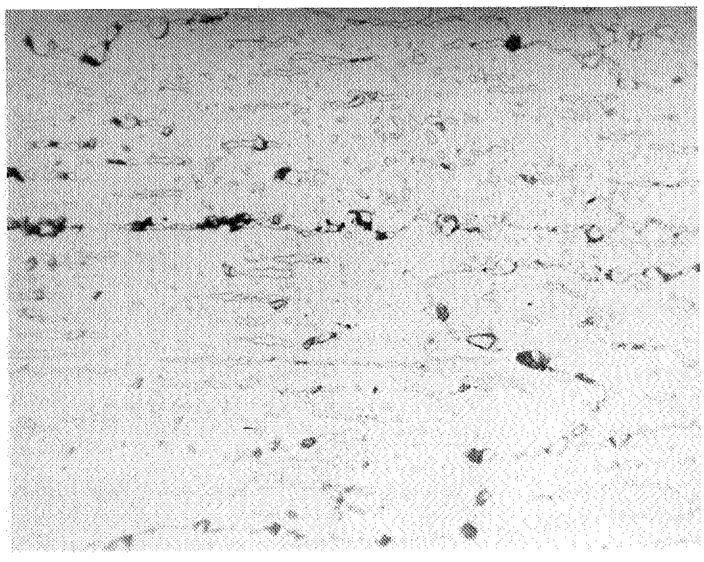

Figure 14. Creep deterioration beyond tip of crack shown in Figure 13 (mag. 300x).

We may add that, to date, tube failure has not been a disturbing factor. Since startup, only one tube has failed by longitudinal creep fissuring.

In carrying out the inspections described in this article easily the most useful means of non-destructive testing has been dye penetrant testing. This has enabled us to detect many weld defects before they have had a chance to progress to catastrophic failure. The second most valuable non-destructive tool has been gamma-radiography. The two methods are complementary rather than supplementary, in that dye checking has revealed many defects not shown by radiography, and vice versa. Attempts to assess the tube bores by examination with closed circuit T.V., or by illuminated mirror and telescope, have not been informative. No attempt has been made to use eddy current methods in situ, although some laboratory experiments have been done; so far these have only indicated that a patch of bore oxidation, at a stage not considered dangerous shows, on the equipment used by us, as big an effect as multiple creep fissuring right through the tube wall. For the immediate future, therefore, we propose to continue our inspections placing a heavy reliance on dye checking and gamma radiography applied as our experience, and that of other operators as we learn of it, dictates.

Acknowledgment

I would like to thank African Explosives and Chemical Industires Ltd., for granting me permission to write and publish this article, and my collegues, particularly R.E. Leyman and J. Martin, for their help in preparing it. #

Literature cited

1. Jacobwitz, J.L., and L.A. Zeis, *Safety in Air and Ammonia Plants,* A CEP technical manual, 11 (1969).

TUCKER, A.J.P.

DISCUSSION

HAYS MAYO, CFCA: I'd like Roger Newton to tell us how long he's been operating with cracked welds.

ROGER NEWTON, Commercial Solvents Corp.: In February of last year we investigated a number of welds and found what we thought were some cracks. We made a complete investigation of all the upper welds in the tubes in July and August, 1970. We started up with 47 welds known to be cracked. We shut down for a regular shut down this year, X-rayed the same welds and the operator did not know that he was inspecting only cracked tubes. He found roughly 90 per cent of those with the catalyst still in place. We took out the worst one, sectioned it, looked at it; the other 46 are still in service and we expect them to be in service for two or three years.

TUCKER: I'd like to ask Ken Lowstetter to make a comment. When we make a new weld in a tube, we radiograph it thoroughly and if we've got the slightest crack we reject it. But we apparently are operating now for something like three years with cracks going up to 50% through the tube wall. Are we wasting our time on weld inspections and radiography?

KEN LOWSTETTER, Abex Corp.: I'm delight, Tony, that you put me on a spot of this nature because we x-ray tube welds by the thousands, I have proclaimed for a number of years that with reproducible welding techniques and procedures that 100% radiography is not a necessity on reformer tubes, although being a manufacturer, if the customer desires this we have never refused to do it.

Now I feel certain that when you start a new procedure or use new materials or new ways to weld, 100 per cent radiography is justified in that you have to prove the procedures that you're using. Dr. Newton of course has come up with something that no one ever dared to do before, such as allowing tubes with cracks to run, and although he didn't mention it, there are other changes that he has made in this furnace.

Q. You left Dow's running, Ken.?

LOWSTETTER: That's right. But he changed his temperature limitations tremendously, and I think the x-raying of welds in this case was used as a safety factor so that if there were slight overheats or the furnace cooled down rapidly and produced strains, then failure would not occur immediately.