EXPLOSION IN THE FEED-GAS SECTION OF AN AMMONIA PLANT

Since vessel cracks may occur in spite of all precautions, it is important to inspect welds in attachments and points of attachment at least as carefully as the main seams in a shell.

A. Cracknell
Imperial Chemical Industries, Ltd.
Billingham, England

Every few months one hears reports of vessels that have failed on hydrostatic test, and there must be many cases that are not reported. Much engineering progress has stemmed from investigation of failures, and it is important that the details of these incidents be disseminated as widely as possible to minimize the chances of reoccurence.

Hydrodesulfurizer design and fabrication

The No. 3 reformer hydrodesulfurizer at Heysham, England cracked in a brittle manner over a 15 ft. length during a recent hydraulic test, Figure 1. The vessel was 7 ft. 6 in. dia. x 17/32 in wall thickness, and about 50 ft. tall.

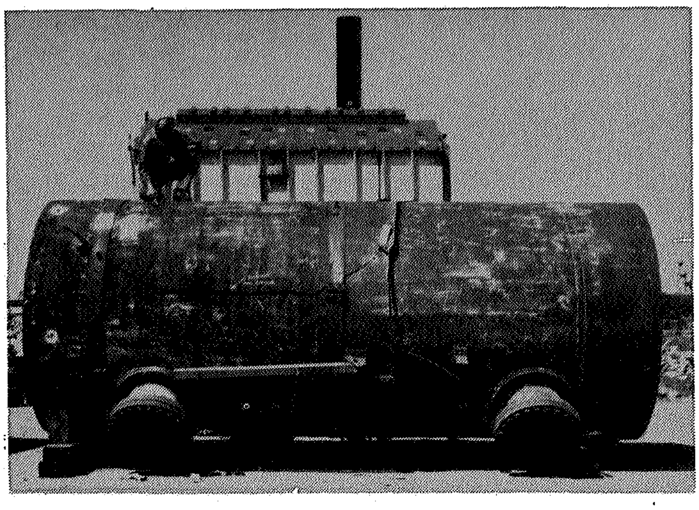

Figure 1. The ends of the cracked vessel have been cut off and straps fastened around it to allow removal from the plant.

It was made from Colmo 950 which is a 1% Cr ½% Mo creep resisting steel and when it was new, ten years ago, it was stress relieved and hydraulically tested to 600 lb./sq. in.gauge. The design and fabrication was to BS 1500, i.e., similar to the old ASME VIII. It operated at 400°C and 300 lb./sq. in.[2]. A few months ago part of the vessel was grossly overheated when an attempt was made to burn out carbon from the top bed of catalyst by passing oxidizing gas up the vessel. To reclaim the vessel a 5 ft. length was cut out and the vessel shortened by this amount. Welding was followed by a local stress relief and a hydraulic test with water at a temperature of 13°C. The test pressure was fixed at 540 lb./sq. in. in view of the partial loss of the corrosion allowance, and the vessel had only been at this pressure for a few seconds when it failed by typical brittle fracture, Figure 2.

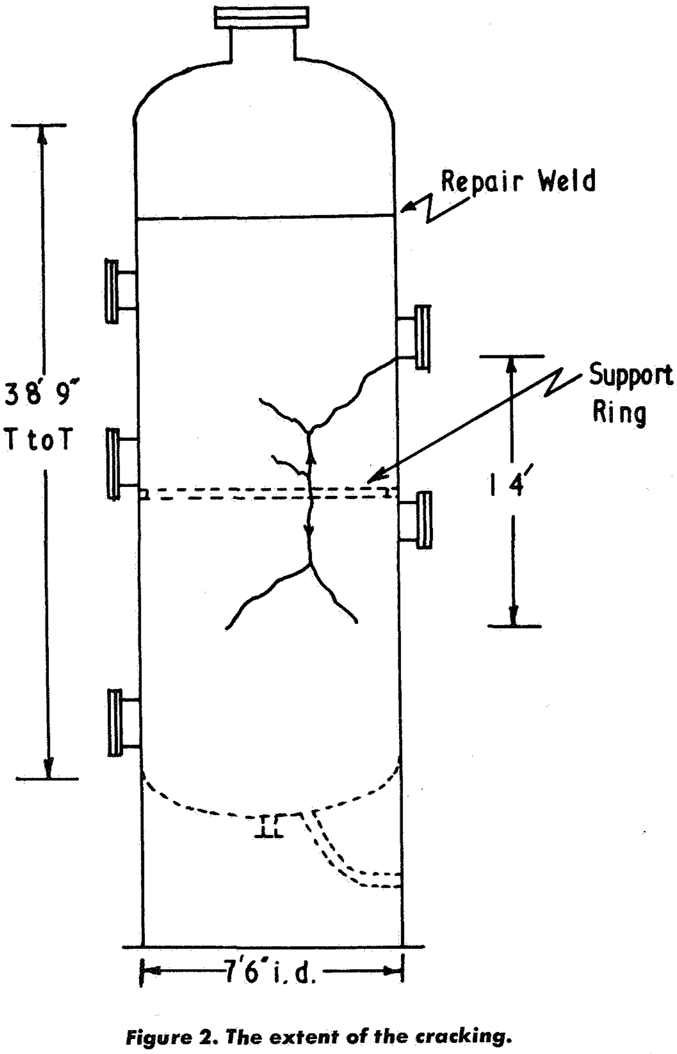

Figure 2. The extent of the cracking.

The failure initiated at a point at least 10 ft. from the part of the vessel which had been affected by the original overheating or by the repair welding and local stress relief. The overheating is considered to have had no significance in causing the brittle failure except that it gave reason to pressure test the vessel.

The fracture origin was a butt joint in the lower catalyst bed supporting ring, Figure 3. This ring was made of 1½ sq. in. Cr Mo bar and, for ease of fabrication, was put in the vessel as two half circles. The two halves were fillet welded to the shell with continuous fillets, but the contiguous ends of the bars were not welded together to give a continuous ring. The narrow gaps between the bar ends were joined by a weld bead, but no attempt had been made to produce a full penetration weld. This left a large built-in

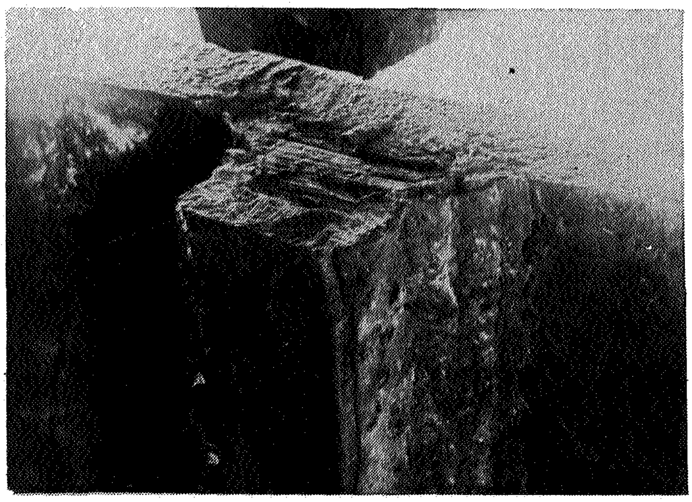

Figure 3. Photo of the crack origin. The unwelded (flame cut) end of the catalyst support ring can be seen beneath the weld bead used to cover the gap in the ring.

crack or notch with its axis parallel to the axis of the vessel, and in the plane of maximum stress. Moreover, this built-in notch was connected via the fillet weld to the shell of the vessel. This was the direction in which the crack propagated and led to the failure.

It is now clear that growth of the crack which caused the failure did not occur in one stage at the time of hydraulic test but that a crack had propagated part way through the wall either during manufacture or in service.

The vessel had a second support ring, higher up, again with two gaps in it. Examination showed that there was a serious crack in the shell at each of these and also at the gap in the lower ring at 180° to the gap which caused failure. Examination of the hydrodesulphuriser on No. 4 reformer at Heysham, which is identical in design, manufacture and service, showed that at each of the four gaps there was similar cracking. Fig. 2 shows the extent of the cracking at one of the other gaps in the failed vessel.

The cracks in the shell plate were readily shown up by radiography and by ultrasonics, but magnaflux on the inside was very unreliable in picking up the cracks.

The (unfailed) crack shown in Figure 4 extended 15 mm. into the 31 mm. thick shell, and was 40 mm. long. The extent of the crack which caused failure could not be accurately estimated. It is clear, however, that the failed vessel was severely cracked and the result of the hydraulic test could have been predicted if there had been any reason to suspect cracking and to examine the areas in detail. The cracks in the No. 4 vessel were 6 mm. deep. The support ring has been cut back, the cracks ground out, smoothed off, and the vessel returned to service.

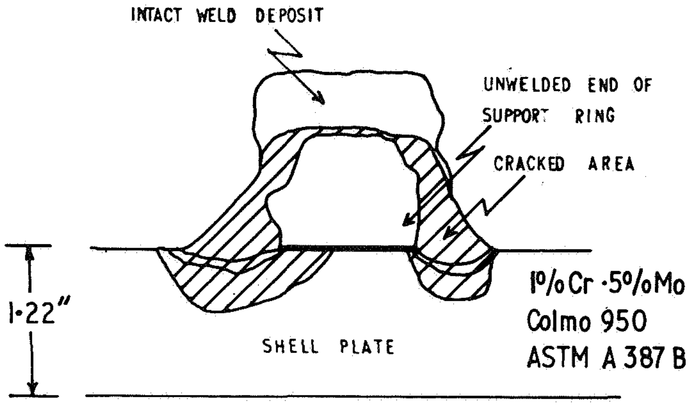

Figure 4. Profile of crack at support ring joint 180w

Causes of failure

It was quite clear that this vessel failed from a crack which was present before the final pressure test. Cracks may of course form during welding, during heat treatment or in service. Microexamination, however, showed that the cracks had formed by cleavage, and were filled with oxide scale which could not have formed during service, thereby eliminating creep as the primary cause. It is probably that they were produced during fabrication/heat treatment, but were small enough to be stable during the initial pressure test at 600 lb./sq. in.gauge. Since the vessel failed at 540 lb./sq. in. gauge, it follows that in service either the crack grew by creep or the toughness of the material (which determines the size of the crack it can tolerate) must be reduced.

Impact tests on pieces of plate a few inches from the crack causing failure showed 30 ft. lb. Ch.V at the failure temperature, 13°C. There is no data on the original impact strength of the plate: it may have been higher, but 30 ft. lb. is quite a reasonable value for a 29 ton Cr/Mo steel.

Even if the impact properties did not deteriorate in service, the fracture toughness would be reduced by the 1cc./100 gm. or so of hydrogen that would be picked up in service. The effect would not be large in a steel of this strength, but could be enough to convert a sub critical crack to one that could propagate spontaneously.

At least one firm has regularly inserted support rings by the technique which gave trouble on the Heysham hydrodesulfurizers, and there are probably many vessels which have undesirable notches and perhaps cracks.

Clearly a pressure test at ambient temperature should be done only after a very careful examination of such vessels have been either in service with hot high pressure hydrogen (so as to dissolve more than 0.5 cc. H_2/100 gm. metal) or at a temperature at which cracks could grow by creep.

Preventive measures

It is equally important to prevent cracks being present in the first place in any future vessels. To do so:

1. Joints in support rings or other attachments should be made with full penetration welds.
2. Preheat when welding attachments should be as carefully controlled, as when making main seams.

3. Thermal stresses arising from inserting an alloy steel vessel into a hot furnace for stress relief can be sufficient to cause cracking. The allowable temperature must be a matter of judgement and experience, but can be below 100°C.

4. In spite of all these precautions cracks may occur. It is important therefore to inspect welds in attachments and points of attachment at least as carefully as the main seams in a shell.

The risks are greatest with alloy steel vessels, particularly if they are thick walled. The usual still, absorber, or stripper column is much less likely to be a risk even if the tray supports have the undesired notches in them. Nevertheless, the areas in question are being given more attention during inspection than has been done in the past, and support ring details for future vessels will be given very careful consideration.

Cracknell

DISCUSSION

Q. Was that a transverse crack?

WILLIE CLARK, ICI: All cracks were transverse to the catalyst tray support rings - that is to say, longitudinal to the axis of the main shell.

Q. And was the thing stress relieved after welding of the bars?

CLARK: Yes; it was fully stress-relieved, and I don't think there's anything wrong with that. There were no significantly high hardness found anywhere.

JACK THOMAS, Standard Oil Co. (Ohio): We have built Hydrocracker reactors of 2¼ chrome and of 1¼ chrome. These are stress-relieved several times in the course of fabrication and repeatedly we'd find cracks at the toe of the support bar welds. These occurred during the stress-relieving which necessitated our Magnafluxing of all these weld after each and after the final stress-relief. Was this done by you?

CLARK: These were bought in 1960, when we weren't as wise as we are now. Now I accept what you say entirely. Inch and 5/16th thickness is not particularly dangerous, perhaps, but now we would do magnaflux on anything we thought significant after stress-relief. But these vessels - it's pretty certain they were not checked after the stress-relief.

Q. Was an examination made of the lower part of the shell, after its overheating? When the area where the crack had occured, to verify that there'd been no damage from that overheating incident?

CLARK: It's not recorded that there was any careful examination. It was known that the overheating had been confined to the top part of the shell, from the amount of scaling and everything else, and quite certainly, this lower support ring- there was no reason to believe it had been more than warm. And people looked round it, but they didn't magnaflux things. Next time, they will.

Incidentally, a thing I didn't mention was, the pressure testing temperature was 13 Centigrade. At that temperature, the Charpy Vee toughness of the steel was about 30 foot pounds, which is not at all bad. If you do get 30 foot pounds, unless you're very modern, you think you're on a good wicket. But it wasn't good enough.

Q. Were you suggesting that the presence of hydrogen at - at this relatively low pressure and temperature - mostly the temperature, really - caused some - some embrittlement? I think this is somewhat controversial, isn't it? It's - we - could you expand on that?

CLARK: It is a little controversial. We've got to find some reason why the thing blew up at 540 pounds, when it had previously stood 600. I believe Mr. Karinen - the investigation that was carried out for him brought to light some papers indicating that moderate pressures of hydrogen could reduce the toughness.

Now here, in this case, you had a quite serious, we think, original crack. Not bad enough to ruin it during the original works pressure test, but if you've got something that is very near critical, then it only needs a last straw on the camel's back, and 5% of hydrogen may be enough to do that.