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A.J.P. TUCKER, African Explosives and Chemical Industries, Ltd.: I'm not going to talk about tubes at all, but about welds. African Explosives operate a 600 ton/day high pressure Kellogg furnace. The catalyst tubes and risers are HK 40, four inch bore and one inch wall thickness. They are all attached to the bottom headers by weldolets. The bottom headers are Incoloy 800. The welding on the bottom headers and weldolets is done in Inconel 82 root run and Incoloy 182 weld out.

In February of this year, after about 18000 hours' service we had to shut down the plant prematurely just before a planned shutdown because we saw a leak near a bottom header. On examining this area we found that a butt weld in the bottom header had cracked all around the top half.

We then stripped all the lagging from the bottom headers and examined every Incoloy 182 weld. We found that another of our butt welds had virtually completely failed, although it hadn't leaked. We found two welds between the manifold and weldolets had virtually cracked all through at the bottom of two risers. We then examined every weld in this area and found that every weld was cracked.

The cracking was not necessarily at the surface. Welds showing no surface cracking were examined after a little surface grinding and we found interior cracking everywhere we looked. We then proceeded to repair about 170 welds by grinding, dye check, grinding, dye check, to see that we had got all the cracking out. The average depth was about five eighths of an inch before we were sure we had all the cracks out. So this cracking starts subsurface but not at the root - it starts somewhere in the middle of the weld and tends to proceed more rapidly to the outside, as far as we could see, then towards the inside. The cracking was revealed by ultrasonic inspection but when we inspected this way and found indication of cracking in every weld, I refused to believe it.

We repaired the welds as best we could at the time and went on line probably with some cracked welds. Incidentally, we did cut out some welds completely and every sample we examined, whether it showed cracks or fissures or not by dye check, did show minor fissuring under the microscope.

There was an indication of intergranular deterioration in every weld we examined. This was as I say, after a running time of roughly 18000 hours and we feel from this that the life of Incoloy 182 weld metal is going to be for us a more severe limitation on the life of the plant than the life of the reformer tubes.

We have done our repairs largely with 182 which is all we had at the time and then we did manage to get some Inco A which we did some repairs with. In February of next year we will probably have another look to see how these repairs have done.

As far as I can tell from a survey of various authorities nobody is prepared to say that there is an appreciably better weld material than Incoloy 182. I would appreciate personally any comments from the floor on what is the best method of welding up a complete harp.

We have, for other reasons, ordered a complete set of tubes and manifolds, and we're in the position of now having the tubes made and we don't know how to stick the whole lot together into harps.

DISCUSSION

JACK THOMAS, Standard Oil Co. (Ohio): The question I have for the several people that have given data is that are not your failures in part explained because the tubes were designed on the basis of average 100,000 hour life which in fact would give you only about 20,000 hours for minimum life? Are not design stresses really too high for the expected 100,000 hour life for all tubes? I'm afraid that we identify every failure with something wrong with the material, and I am wondering if many tubes were not just overstressed beyond the life - I mean, overstressed for the life we expected to get. We expect 100,000 hours, and you design on an average for 100,000 hours. You're not going to get all the tubes giving you 100,000 hours.

KEN LOWSTETTER, Abex Corp.: I'll give it a start. Number one, I know considerable data has been accumulated on the HK-40 alloy, and most of the engineering companies who design tubing have this data, therefore, they have picked their own criterion. However, I believe prime consideration must be given to the fact that all collected data comes from laboratory tests at steady state conditions. Anyone running a reformer furnace knows that it does not operate under steady state conditions.

There is also sufficient data on stress rupture testing that strongly indicates fluctuating temperatures increase the rate of creep, specifically the second stage creep rate. Hence, if tube walls are subjected to fluctuating temperatures, and there is any restraint in the tube, there is bound to be some plastic flow which in turn will increase the creep rate. Hence, you can have a rupture sooner than you expected because your rate of creep is higher than was predicted by the original steady state conditions.

Thirdly, we predict stress rupture on a 100,000 hour basis and know that the tests on 21 or 22 thousand hours was in third stage creep. A great deal of data has been extrapolated in this manner and it has usually worked just fine.

However, one of the things that hasn't been considered is how fast third stage creep progresses after 20 - 22 thousands hours. Hence, the rupture life being experienced results from fluctuation in temperature on material in third stage creep, and this we don't want in any kind of operation.

Q. Where there were tube failures, was the design stress creep rupture for 100,000 hours a minimum or was it an average?

GEORGE KRATSIOS, Foster Wheeler Corp.: If my memory serves me correctly, the tubes for Olin were designed on the average stress to produce rupture in 100,000 hours. I don't have the calculations with me. In most cases the customer either specifies the stresses or the thickness for the tubes.

In the cases of the Foster Wheeler design, we still design for the average stress to produce rupture in 100,000 hours. But we give more emphasis on the temperature, for which the tubes should be designed, and knowing that the stress drops very rapidly as the temperature increases, we like to make sure that the proper design temperature is used. The design temperature we use is the maximum calculated tube metal temperature plus 50°F.

Recent experience, however, indicates that in a few cases and for various reasons such as overfiring or catalyst inactivity, the actual metal temperatures have been higher than the design temperatures.

L.A. ZEIS, M.W. Kellogg Co.: A good part of the early furnaces which were included on Bill Salot's summary were designed on the basis of 50% of the stress to produce 1% creep in 10,000 hours. There was no reference to rupture life. The more recent furnaces have been designed on the basis of 75% of the average stress to produce rupture in 100,000 hours. That also is equal to 100% of the minimum stress to produce rupture in 100,000 hours.

So a good part of the failures cited were in tubes which are thinner than we'd be designing today. You can't say generally what the expected rupture life would be, because the creep and rupture curves cross. Each furnace would have to be calculated individually to compare the expected life. So your question is answered yes, some of the tubes are thinner than they would be if they were designed to the minimum 100,000 hour life.

One other point on that question is that in comparing the expected life of HK 40 material, note that a difference of 140 degrees can mean the difference between an anticipated rupture life of 10,000 hours and an anticipated rupture life of 100,000 hours, based on parameter calculations. So tube life is temperature sensitive especially at these elevated temperatures.

Incidentally, if I may add one thing, in the earlier cases of overheating failures reported to us, we have calculated the life based on reported temperatures to which the tubes were exposed. These temperatures were in most cases verified by metallurgical analysis. If we calculate tube life using the same parameters we get the same life that the tubes have in service, give or take a few months.

SCHARLE: Well, to just briefly repeat again, in our history, the six failures that we had that - of course were not involved with what we had called hot spots in the first place, so you can't even enter those into this particular argument. But in those particular tubes that did have a history of higher than normal operating temperatures, we tried to make that same sort of analysis on these curves, and it didn't even come close. I think it only predicted that it only had one third of the life it should have had. We also made some metallurgical examinations to determine to what temperature the specimens on the hotter tubes that had failed had been heated and I think the highest we had gotten was 1750 degrees. So from our point of view, our analysis couldn't begin to explain the failures just based on those curves, even taking into consideration the 75% design stress factor which would take into account the difference between the average life and the lower part of the failure scatter bend.

ARTHUR D. MERRITT, Sun Olin Chemical Co.: We have a low pressure reformer on which we've been measuring the diameter of our tubes. Last year in Portland there was some mention of a two or three per cent growth in the circumference of the tube as being a possible indication that tubes should be replaced. I wondered what experience people have had with this or what people were using as a guide for tube replacement using the dimensional growth as a basis.

And I also wonder if Mr. Holloway's comments about measuring the magnetism in some areas where he had not seen growth sheds some doubt on this as a basis for predicting tube life.

LOWSTETTER: I shall give you our only experience on a hydrogen reformer furnace that ran some 35,000 hours. I examined macro-etched sections of the tubes in areas where there were not ruptures. The total elongation measured on circumference was approximately 17%. In areas adjacent to where rupture had occurred you could put the original as-cast tube inside the tube that had ruptured - approximate elongation 26%.

Now, if you base your criterion on ductility, or elongation, you have two separate cases to consider. You have the amount of the elongation the metal will withstand at room temperature, which is considerably different than the second choice of what it will take at the operating temperature. Therefore, if you look at the aged material, you would expect one or 2% residual room temperature elongation. However, if you examine data for short time hot tensile tests you'll find that the HK-40 material after it operates above 1400°F may have as much as 20 to 25% elongation. So the problem is strictly twofold, one of elevated temperature elongation or the elongation that has taken place at temperature, and the second, the elongation at room temperature after it has been exposed. Both effect service life, but under different sets of conditions.

Therefore the reasons you get a figure of two per cent is obviouse because it's what we expect from the material after it's been exposed to elevated temperatures for considerable length of time in a room temperature test. This being the smaller figure it governs for allowable ductility.

Q. Do you mean by this that in the high pressure reformer that in areas not affected by the actual rupture that there's a negligible elongation?

LOWSTETTER: I don't think I said that. I said the opposite. There can be a change in high pressure, but low pressure furnaces have obvious amounts of elongation.

Q. All right. How much is there?

LOWSTETTER: Well, again, the problem comes down to which of the measures of elongation is an actual case, be it either case, take laboratory data and use it for the standard. If you use laboratory data, the rate of strain then becomes very important and it must be considered. So it's difficult to actually predict because you don't know the rate of straining in the furnace tube. In a stress rupture test the strain rate or creep rate is known before failure begins, and normally this is quite low.

With a very low rate of strain, there would be very, very little ductility or movement. Before actual cracking the metal goes through the 3 stages of creep. Fissuring would eventually open up in second or third stage. If it was subjected to a higher strain rate, the chances are the elongation would be less because the time in any creep stage would be shorter.

Q. In the intermediate pressure reformer, in an area a few inches below the actual rupture do you find any appreciable change in dimensions?

LOWSTETTER: We found a change in tubes that have run 35,000 hours. Some distance away from the rupture we found 17% elongation, and we're not sure how far this was from the rupture. It was something like 12, 18 inches. In the area immediately adjacent to the rupture, but away from the actual crack itself, we compared a piece of tubing from the original casting with the used one. The original tube would fit inside the used tube. In other words, the ID of the used tube was as large as the OD of an originally cast tube.

The tube had expanded this much. Incidentally, these tubes were bored originally.

M.W. CLARK, Lummus Co.: One of the dangers that we have in looking at data and design curves is that we tend to forget exactly how these data were generated. Ken Lowstetter said to begin with, remember, that these curves are made under creep rupture test conditions in the laboratory, under controlled conditions, i.e., under steady state.

If you look at the actual creep rupture curves that are generated as a result of these tests, you get a little bit of a look into what is happening. We have three stages of creep that take place. The first stage is more or less responding by what you would consider an elastic response. Then there's a long drawn out second stage, and then a rather rapidly increasing third stage creep.

Now at the beginning of the third stage of somewhere in here you begin to get actual rupture in the specimens. So what we're really looking at is how to be able to predict at what point in time of an operating unit the beginning of third stage creep sets in. If you look at the complete creep curves for a relatively short time, eight to ten thousands hours, at the ones for 20,000 hours, and at the 1,000 hour ones, you will find that with the onset of third stage creep you have a certain elongation or a total creep. Let's use the term strain which is probably a better one. The total strain in a short time test (that is, a high stress applied for a short time) is generally much greater than the strain at third stage onset in a long time test.

Now if you're going to look at what the dimensional changes of your tube are in service, you must first know when this tube is going to break before you can say what the significance of this dimensional change is. A tube that is going to break in a short period of time for whatever reasons (higher temperatures or higher pressures than for which it was designed, etc.) is probably going to have a larger diametric increase before it goes into third stage creep than one that has gone for seven or eight years.

At what point are you going to retire this tube on the basis of dimensional changes? You have to know the answer to your question before you can give this dimensional retirement point. Now this figure of two to three per cent generally comes from looking at the long time creep rupture curves, that is, the total curve, and trying to predict in some rational manner where the extension or the strain is going to be in a test that has run to a reasonably average time representative of the time you're trying to get out of your tubes.

When we consider curves for several years, it looks as if we should be looking at a two per cent limit. If the 2% occurs in one year, obviously you're not on this curve. So it's not just as simple as quoting 2%. The technique of measuring repeatedly, plotting the increase or plotting a curve of this measurement and then when your rate begins to accelerate, you know that you're beginning to enter the third stage creep. The unfortunate fact of ife is that you probably don't have time to the next shutdown before you should take this tube out of service. It may not do you an awful lot of good unless you can shut your unit down every three or four months.

There have been units which have been measured on this basis that have had to be shut down for other reasons, and this technique appears to be valid. If you get an opportunity to frequently measure the diameter of the tubes, you find that they do gradually increase in diameter (your measurement has to be very accurate to do this). They eventually start to increase more rapidly, and this is the point that you'd better have extra tubes on hand.

This is not necessarily a practical economic way to run a reformer unit. I'm not promoting it. These are the problems that the operators are up against, and these are some of the problems that the designer faces when he is trying to anticipate the mode of operation.

Q. What type of weld and what procedure do you recommend for making works of soldering with materials static HK 40 usage with fittings of new materials of the same specifications?

KRATSIOS: If I understand the question, you want to know what we would recommend for weld rod in welding HK material that has been in service to new static casting HK material?

Q. But this new material would use a material of the same specification.

KRATSIOS: The same specification?

Q. HK 40?

KRATSIOS: New static casting to old static casting?

Q. Okay.

KRATSIOS: HK material. Well, we would first of all recommend, if at all possible, to remove the affected area of the material that has been in service so you wouldn't have to weld on the heat affected zone. Then we would recommend buttering up the joint of the old material by depositing INCO 182 weld and then using INCO 82 for the root pass and INCO 182 for the cover pass.

WILLIE CLARK, ICI: I would like just to raise a point which I think I raised here four or five years ago, a matter which has not been much discussed yet. I would like to tell you what has happened, and say, why don't you do something about it? This is pigtail nipping. If you remember, when we started reforming naphtha, we had furnaces - 200 pound furnaces which had in them exit pigtails, and we conceived the crazy idea of squashing these flat while the furnace was running if the tube began to leak.

And against a great deal of opposition from people who said it was dangerous, we started to do it. The first time it was done without the Works Manager knowing, and he could not complain of the results and so it has been done since then, I think it is three or four hundred times on those furnaces, and it saved my salary many, many times over for as long as I am likely to live, because the furnace is not shut down, and it goes on running at full rate and by the time you have nipped 25% of the 200 tubes in the furnace, they are stilling running at 120% flow sheet, and plant operators say, well, what does it matter if we do overheat a tube? We can just nip it and go on.

Now when we got three thousand ton Kellogg units, we persuaded Kellogg's that this was a good idea, and we agreed with them how to do it on a Kellogg furnace. And we have now got a little experience. Firstly, it has not been entirely satisfactory. We have had about six or seven tube failures and we have nipped these tubes off with the plant on line without any serious trouble, but failures of the exit pigtails caused by bad fabrication and rather too tight design have caused nearly as many shutdowns as nipping has avoided.

You can open the bottom of a modified Kellogg furnace, and I don't see why it shouldn't apply to any other furnace, put a pigtail nipper on to the hot pigtail without getting yourself burned, without a great deal of trouble.

We are at the moment getting a big Foster Wheeler furnace, and that will have provision for access to the pigtails at the bottom so that they can be nipped.

Now when you can nip off a pigtail, it means that if a tube goes you're not embarrassed. You don't lose $50,000 for the incident. You carry on running a tube short or maybe it's two tubes short until your next annual shutdown when you can usually put in the replacement tubes without extending the shutdown.

Ideally, it's just conceivable you could run for 100 years by which time you would have changed all the tubes around three times over but you'd never have shut down for a major tube turnaround. But certainly if you work out the figures, you'll find that you can spend a lot of money, say $100,000 easily in modifying your furnace so that you can get bottom pigtails in, and you can very quickly recoup this cost. Even if you don't get your first tube failure on line for seven years, you still make money from having spent $100,000, to put the pigtails in in the first place.

I am very surprised that no one is showing any interest in this. We actually have a patent on the procedure, so I rather hoped that people would take it up. It is possible and it can save you money.

IAM MCFARLAND: ICI AMERICA: Hays, may I come in very briefly on that one? As the sort of resident representative of ICI in the United States, I think over the last three years I think I've had three requests for information on this. And the licensing basis - I'm not trying to get commercial, if anybody is thinking this - the licensing basis based on what you've got in the way of what might need to be met. And people say, well, thank you very much; we now know how much it will cost us. We'll wait till we have a failure. And when the failure comes, they probably do something else about it.

But recently queried with our people in the UK if anybody in the USA had ever done this, and the answer is no, they haven't.

Q. About P.K.'s of the material HK 40, is it possible by some chemical treatment to obtain original characteristics?

CLARK: I assume that I understand the question. This is one that keeps coming up; and that is, when you have operated a unit for some period of time, you have metals in them that have been underoing whatever metallurgical changes take place which get us into problems when we want to repair and join them and what not. Now is there any means by which you can condition this material to bring it back as to the original - "as cast" properties.Is that the basis of the question?

And the answer is no, other than putting it back into a melting furnace and spinning another tube out of it. The changes that take place during aging of a cast structure at the operating temperature one not wholly reversible by any heat treatment. You can improve the weldability by heating at 1250°C but this does not regain the full strength of the as cast tube.

MAYO: I believe it would be of interest to many of the people who are faced with shutdown inspection in the near future to have some review by design people as to direct mended method of examination, a detailed examination. Larry, would you go through this for the recommendations for the Kellogg type units?

ZEIS: Well, I thought if we'd first restrict it to the tubes, it would be more general.

MAYO: Go ahead.

ZEIS: As far as inspection of the tubes themselves when the furnace is down, I think there are two primary questions on the owner's mind: one is, are there any defects which are going to shut this furnace down as soon as I start it up again; and the second, which is one that Ken Lowstetter has been talking about and working with, is how much life is left in these tubes as they set?

Getting back to the first, as far as defect detection is concerned, in areas of known hot spots based on operator's logs and observations, we would say that radiography of the welds would be indicated nondestructive testing step to take in these hot zones.

Radiography works best when the catalyst is out of the tubes. Radiography with the catalyst in the tubes can be very misleading and you're most likely to miss something that is there. Dye penetrant testing applied to the tubes has not shown up very much because of the roughened surface. It's a big chore to try to cover 100% of that surface, and dye checking of the welds has also not yielded very much because the typical weld defect in a cast tube originates either on the inside at the root or in the center of the weld and you don't see it on the outside.

The magnetic check which we heard about earlier today is one that I think you'll have to draw your own conclusions as to its value. It certainly has found suspicious areas to say the least. I believe many of you are using this method. There is a question of interpretation of the results but the simplest step seems to be to cut it out and see what gives that terrible signal. Visual examination is something that certainly should be done at every shutdown and by the same people each time to see the difference in the appearance of the scale and the color of the scale, if there has been any evidence of local overheating or incipient melting. You can sometimes see some very heavy, glassy slag.

We did talk about dimensional checks. Our most recent experience has been that right next to a rupture the diameter of the tube was the same as it had been originally; in other words, the rupture was of a kind where there was no indication before it had let go. It's a difficult thing because most people do not have a log of the original dimensions with which they started. It might be worthwhile starting on a few sample tubes just to see how these diameters are changing.

Pressure tests with an ultrasonic type leak detector - with which one hears the signal from escaping gas, is another good method for finding holes either in the welds or in the castings. there are other methods of examination under study which are aimed at trying to find the initiation of third stage creep. These methods are looking for little fissures in the tubes which normally would not be seen by radiography. None of these are as yet of practical value.

On the second part of what to do with the tubes when the furnace is shut down as far as determining or estimating the length or life remaining in the tubes - I'd like Ken Lowstetter to take over. He has done things like this for users.

LOWSTETTER: If you take a tube from your furnace at a reasonable time before it's seen a lot of life, you then have a reference point. Designate three specific areas in the tube depending upon how your furnace runs, to allow for temperature zones. All furnaces have a hot and an intermediate and a cold zone. In each of these zones I recommend that no less than six stress rupture bars be run at three different temperature levels in duplicate and at different stress levels. Repeat this with a tube removed at a later date - and compare results.

Also a metallographic sample should be run in each one of these areas, and thirdly, the chemistry should be determined. And the chemistry should be determined from base material and the carbon checked on 1/32nd inch layers to see whether you're actually carburizing the ID. If this sort of inspection was done periodically, a year or 18 months apart, and if any decent history of the tube is known, at the end of three such examinations you would have developed some pretty strong data to guide you as to what the rest of your tubes might provide in life.

Now this is not an exact method because all tubes do not run exactly the same. Again, you can pick your tubes according to your own temperature profiles, which you know better than anyone else. Such a method of establishing data over a period of time would provide answers to the four and five year period which some people are questioning. It is a little late to take a tube out now because you lack reference point for comparison. Compare it to original data as an alternate, but it can be misleading.

If you have several reference points for comparison the data will give fairly reliable predictions.

KRATSIOS: I don't have anything to add other than what Larry mentioned. The only thing I can add is that good monitoring of the temperatures during operation is very important and that calibration of the instruments that are used for reading the temperatures should be made periodically to assure that the temperatures are correct.

TUCKER: I would like to make a comment on one of Larry Zeis' statements. In my opinion X-ray is about the worst possible way of trying to find incipient defects in your tubes. We have had so far ferretted out seven cracks in tubes, not all of which have been irreparable, and even when we know where these cracks are, which is normally found by dye check, we have not been able to pick up those cracks by X-ray, at least by gamma ray.

Incidentally, to return to an earlier point, we have found that a 1250 degree Centigrade heat treatment prior to welding does enable us to make in situ repairs of HK 40 tubing.