The Detection and Assessment of Carburisation Damage in Visbreaker Heater Tubes

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Abstract. An ultrasonic inspection procedure has been developed for the assessment of carburisation in Visbreaker heater tubes which are manufactured from creep resistant alloys. The work involved an initial site investigation and was followed by extensive laboratory trials. The trials served to correlate ultrasonic responses to carburisation and oxidisation damage in addition to the detection of coke deposition inside the tubes. A management programme has been developed to implement the procedure during a shutdown to deliver real-time results.

Introduction

Visbreaker heater tubes convey heavy hydrocarbon residues from the distillation process through the heater where the product is transformed to lighter hydrocarbons at elevated temperatures. See Figure 1. The tubes are typically 5" diameter, of various thicknesses and are manufactured from creep resistant high Cr material such as P9. An open gas flame is used to provide the heat source. Operating temperatures are several hundreds of degrees Centigrade and excursions can occur to much higher levels. At these temperatures the high carbon levels of the product leads to coking of the internal surfaces of the tubes which causes diffusion of carbon into the parent material and corresponding degradation of material properties.

During shutdowns, mechanical cleaning devices are used to remove as much of the coke deposits as possible, but in practice residues are left behind at the internal upper surfaces of the horizontal tubes. See Figure2. The coke deposits provide a rich source of carbon which diffuses into the material over time and leads to chromium carbide formation. Unsurprisingly, this adversely affects the material properties to the point where fracture could occur under certain thermal transients caused by temperature excursions or start-up/shut-down events. Needless to say, tube failure under the operating environment is undesirable.

In order to avoid such an occurrence, it is standard practice to remove sections of tube material during a shut-down for metallurgical analysis and micro-hardness testing. The extent of carbon penetration can clearly be determined through this process, but it takes several days to complete, especially if repeat samples need to be removed. The heat source in a Visbreaker furnace is introduced through the floor so the hottest tubes are those closest to the heat source, i.e. just above the floor level.

During an investigation, samples are removed from the lower tubes, working up each wall until clear material is found. This could involve several trips to the metallurgical laboratory. If there is any evidence of carburisation tubes have to be entirely removed because affected material becomes too difficult to weld replacement tube onto, and cracking is highly probable. This process can be time consuming and difficult to plan. The chromium alloy tube material is not available ex-stock. Delivery times can be between 9 to 12 months and this can lead to additional problems if material is not procured in advance.

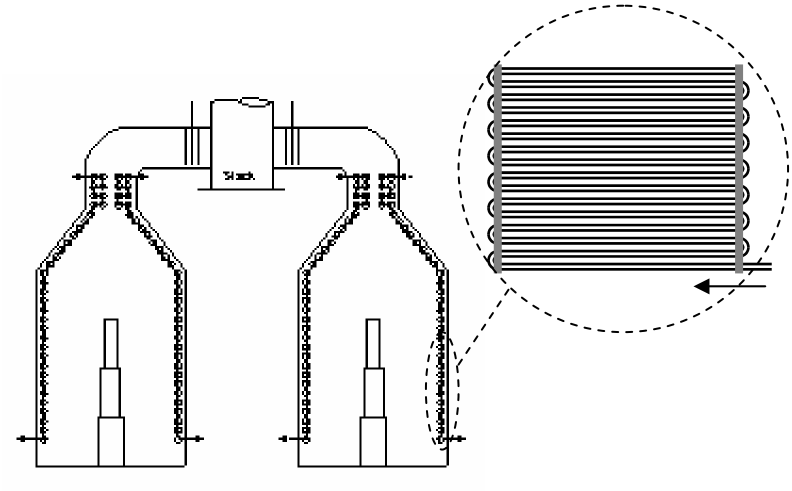

Figure 1. Schematic end view of a twin heater Visbreaker furnace with a side view (inset) sketch of the tube layout on one wall. The heavy hydrocarbons are introduced at the lower section of each wall and work their way up each wall into the flue.

Figure 2. Coke deposit remaining inside a furnace tube after mechanical cleaning.

1. Initial inspection

During 2004, AEA Technology plc received an enquiry from CEPSA, Sanroque Refinery to determine whether an ultrasonic inspection technique was available to detect carburisation levels of approximately 2% in material which would normally have carbon concentrations of maximum 0.2%. It was not known whether ultrasonic techniques had previously been used to determine high carbon concentrations at this stage, but it was known through experience that the Time-Of-Flight-Diffraction (TOFD) technique [1] was capable of imaging certain metallurgical variances such as same-material weld repairs, pearlite banding, segregation, etc. It was therefore decided to attempt the inspection.

1.1 Information provided

- Tubes: 5” ID x 8.1mm nominal wall thickness.
- Carbon levels to be detected would typically be 2% concentration for damaged material compared to 0.2% maximum carbon for unaffected pipe.
- Material was 9% Cr.
- A limited quantity of replacement tube was available.
- Attempts to weld replacement tube onto partially damaged material had resulted in cracking.

1.2 Uncertainties

- The nominal wall thickness was given (8.1mm), but the original wall thickness was unknown. Replacement tube was physically measured at 9.6mm thick.
- Fireside erosion was visibly evident in the lower banks of tubes.
- The extent (if any) of internal and/or external corrosion was unknown.
- The presence of manufacturing anomalies such as inclusions, banding or grain structure variances were unknown.
- The effects of carbon content on ultrasonic velocity was unknown.

2. Initial scans

Figure 3. The conditions inside the heater are less than ideal with sand particles from the sandblasting process in the atmosphere.

Figure 4. An inspection underway.

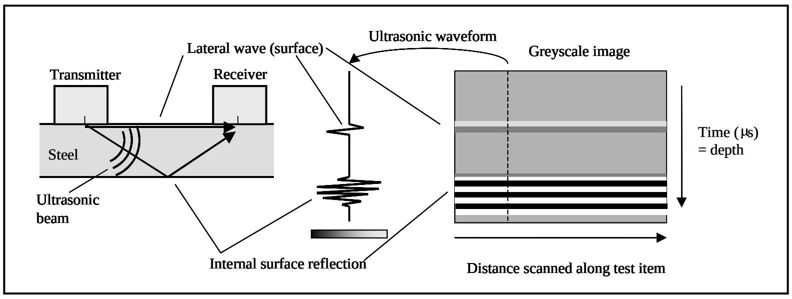

Figure 5. The TOFD technique with grey scale imaging.

The TOFD technique was selected for this inspection as it has the capability to image acoustic scatter from grain boundaries of wrought ferritic products. In fact, one of the most widely used methods for establishing sensitivity is to set the acoustic 'noise' to an amplitude where it is just visible in the image [1]. This is the highest achievable sensitivity as any indication which disturbs the grain scatter becomes detectable. It would be beyond the capabilities of TOFD to measure grain size, but gross variances in grain structure have been observed. Examples include segregation, pearlite banding, microscopic inclusions, creep cavitation and weld repair sites. Contoured wedges were used to provide even contact with the surface and to provide a smooth scanning platform.

Due to the short notice and lack of availability of Microplus equipment the inspection was carried out using a hired RD-Tech Tomoscan which has limited off-line data processing capabilities. The data could not therefore be 'straightened' which would have enhanced the appearance of the data with corresponding improvements for interpretation.

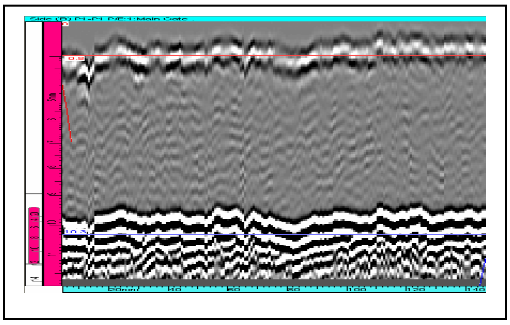

Figure 6. TOFD scan of new pipe, 9.6mm thick. X- axis is distance along pipe. Y-axis is through wall extent. Mottled background is acoustic grain scatter from the wrought material.

The initial scans proved to be very difficult to interpret and it was not until data had been collected from four walls from two heaters that a pattern started to emerge. In fact, the causes of the signals detected was not known at the time of inspection, but it was decided at the time to replace all tubes with detectable signals. The tubes were numbered from the floor counting upwards.

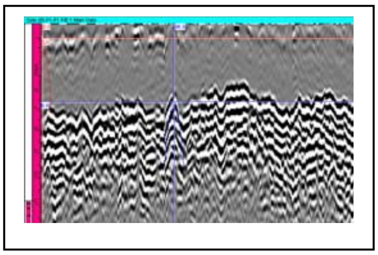

Figure 7. Tube 2

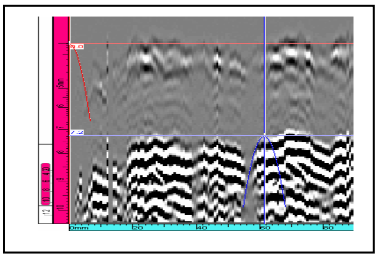

Figure 8. Tube 4

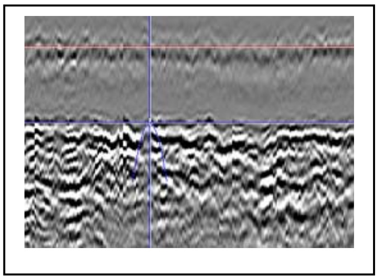

Figure 9. Tube 6

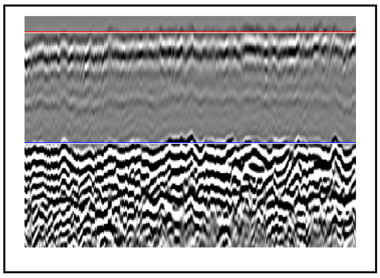

Figure 10. Tube 9

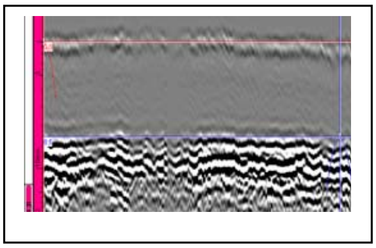

Figure 11. Tube 12

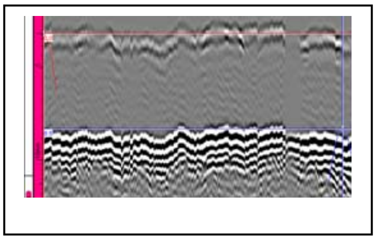

Figure 12. Tube 14

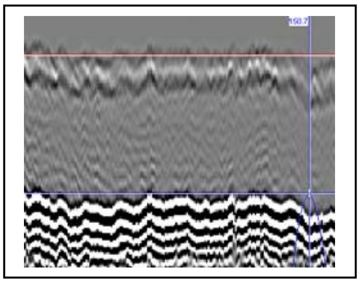

Figure 13. Tube 15. This tube has minor inclusions only. Gain settings and image interpretation are very important to avoid false calls.

Figures 7 through 12 show examples of damaged tube collected on site. Figure 13 shows a tube which is clear of carburisation, but contains minor inclusions only. This was not realised at the time of inspection and the tube was replaced.

3. Post inspection investigation

3.1 Calibration

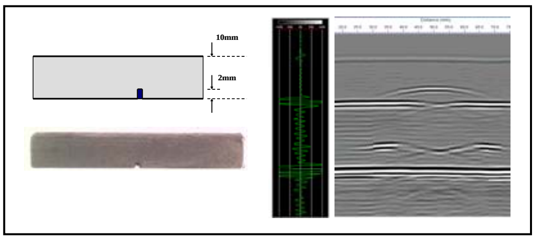

Figure 14. TOFD calibration scan.

A 10mm thick calibration block was obtained of the same curvature as the furnace tubes with a 2mm deep slot. See Figure 14. Calibration scans were collected and the ultrasonic parameters were carefully optimised to give crisp pulse characteristics. The through-wall sizing procedure was established to give precise measurements. The slot could be measured to within ±0.05mm. Note the grain scatter just visible in the background of the image.

The following parameters were optimised:

• Probe type & frequency • Amplifier settings (bandwidth)	• Scanning aids • Scan direction • Interpretation

3.2 Surface preparation

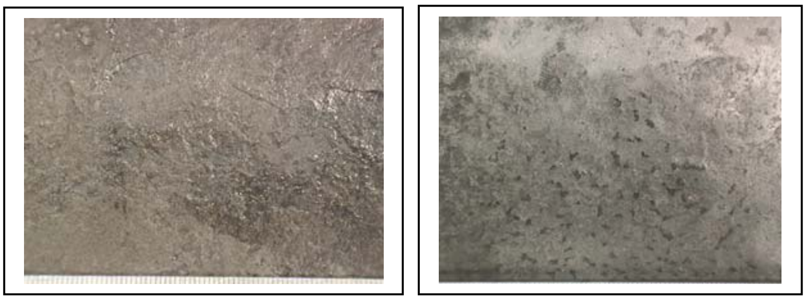

Figure 15. Surface texture comparators

Surface finish was found to be highly important to the inspection. High ultrasonic frequencies are used and these are very sensitive to surface irregularities. Various combinations of grinding, sandblasting, abrasive discs, flapper wheels, and wire brushing were tried until the optimum combination was determined. Comparators were created for site use. See Figure 15.

3.3 Metallography

A number of samples were identified for analysis. Work concentrated on slightly damaged tubes from higher up the walls as the objective was to determine the detection limits, i.e. the minimum amount of damage which could be detected. The samples were scanned using the optimised TOFD procedure and a 10mm wide band of material was removed from the end of each sample for sectioning and analysis. The samples were mounted, polished and etched followed by microhardness testing. See Figures 16 & 17.

Figure 16. Mounted samples.

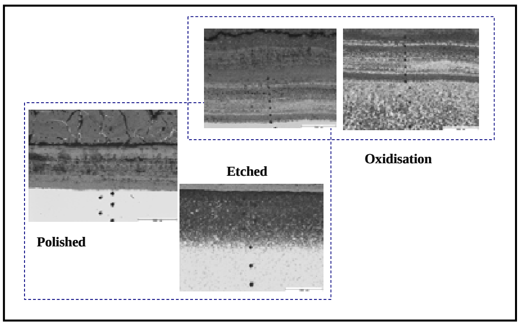

Figure 17. Polished and etched mounted samples

Material close to the internal surface was found to be oxidised and above this a distinct carburised layer was identified (Figure 17). The boundary between carburised and un-carburised material was found to be surprisingly pronounced. Microhardness values also showed a rapid transition between affected an unaffected material (Figure 18). Ultrasonic measurements were able to delineate the carburisation layer from oxidised material and also detect the presence of coke on the internal surface (Figure 19).

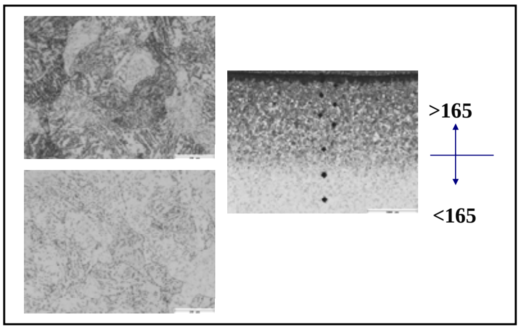

Figure 18. The transition between carburised and un-carburised material. The microhardness indents are 0.1mm apart.

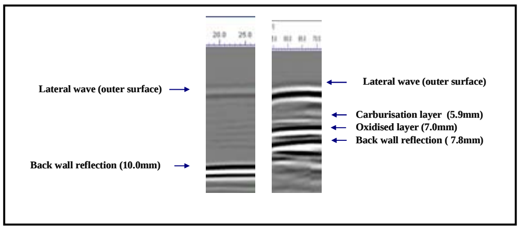

Figure 19. Ultrasonic measurements of the various layers.

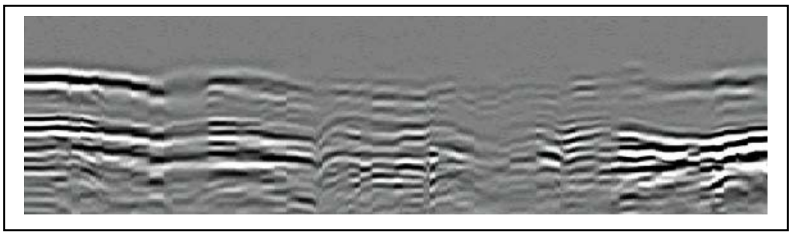

Figure 20. Heavily damaged tube (90° section).

It was found that although the carburisation interface was detectable using TOFD, carburised material was readily penetrated with ultrasound. Through-wall measurements with TOFD are not linear, and although it does not appear to be the case from the images, the lateral wave actually occupies almost 50% of the wall thickness. The lateral wave is exaggerated through the material curvature and surface texture effects. Once the carburisation layer extends into the lateral wave region it becomes undetectable. Therefore, the inspection needs to be conducted with great caution. A heavily damaged section of tube is shown in Figure 20.

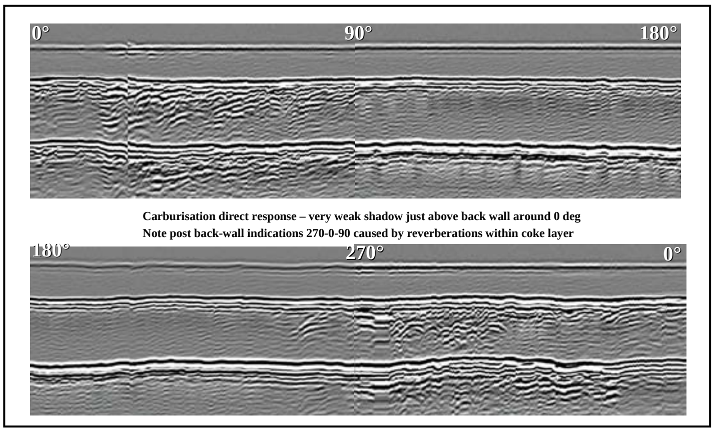

Figure 21. A fully circumferential scan of a slightly damaged tube.

Refer to figures 7 through 9. In all of these images the carburisation interface is obscured by the lateral wave. Figure 7 has a through-wall crack which was detected using a 45°shear wave probe. This technique was initially deemed to be important, but it was soon realised that only excessively carburised material would be cracked, and such material would be rejected as a matter of course. Therefore the detection of individual cracks was deemed unnecessary and this technique was later abandoned.

Figures 9 and 10 show a weak oxidisation layer close to the internal surface. Figures 10 and 11 show a distinct carburisation interface and figure 12 is clear of any flaws.

Figure 21 shows a full circumferential scan of a slightly damaged tube. The carburisation damage is evident as a feint white half cycle preceding the back wall echo around the 0° position. This signal has been observed several times and correlates to 0.5mm penetration of carburisation. Note the post back-wall reverberations in this data which are caused by interference from the coke deposit.

4. Data collection procedure

Sufficient information has been gathered to enable a data collection procedure to be developed which quickly focuses the inspection towards the slightly damaged tubes without wasting undue time on heavily damaged tubes. Tubes are cleaned and sampled at sections, working up each wall. Once clear tubes have been identified the inspection broadens to give a thorough evaluation of the cleared tubes.

Additional tubes higher up the heater wall and across the roof will be evaluated in future inspection campaigns until confidence has been gained in the degradation patterns.

5. Possible future developments

5.1 Diffusion modelling

Although thermal profiles of the heaters have not been evaluated in the context of the ultrasonic examination, there appears to be a strong correlation between time/temperature and the through-wall extent of carburisation. It should therefore be possible to develop a diffusion model which can be used to determine which tubes are at risk. This would enable material to be procured in advance of a shutdown.

5.2 Structural integrity assessment

Once tubes are removed from service, all affected tubes need to be replaced as affected material is problematic to weld onto. From the limited amount of work done, failed tubes observed to date had in excess of 50% through-wall penetration of carburisation. This implies that tubes exhibiting lesser degrees of penetration could be tolerated. A structural integrity assessment could be used to determine acceptance levels for this type of damage.

6. Conclusions

Metallurgical and ultrasonic evaluations of tube samples removed from Visbreaker heaters has enabled meaningful ultrasonic test procedures to be prepared which are capable of identifying tube replacement requirements due to carburisation damage.   This approach provides real-time results and does not require the removal of material for metallurgical investigation, thereby saving time and valuable resources during a plant shutdown.

Reference list

[1] BS EN7706:1993 A Guide to the Calibration and Setting up of TOFD