Chapter

19

Forming Defects

Locations

Forming defects that affect serviceability are generally found in tubes. But beyond this simple fact, nothing can be said about locations, as defective material can be inadvertently placed in any tubed region.

General Description

Failures resulting from manufacturing defects are relatively rare. In fact, manufacturing defects account for less than 1% of total failures examined. Of those that do occur, the two types of defects that are fairly common include seam or lap defects in seamless tubing, and deficient welds in welded tubing.

Seam defects are crevices in steel that are closed but not metallurgically bonded. They may occur in unwelded tubes as a consequence of the presence of internal voids (pipe) or cracks in the ingot from which the tube was formed. Seam defects can also be caused by faulty methods of steel rolling in the steel mill.

Deficiencies in welded tubes are often caused by incomplete fusion of the weldment during the manufacturing process.

Critical Factors

The critical factors resulting in the use of construction materials having significant forming defects include insufficient adherence on the part of the manufacturer to specified fabrication practices or quality control practices and, possibly, insufficient adherence on the part of the boiler manufacturer to specified quality control practices.

Identification

Seam or lap defects appear in a transverse cross section as straight or gently curving cracks, which may run longitudinally for some distance along the tube wall (Fig. 19.1). Although the defect commonly originates at a surface, it may be difficult to see since the surfaces of the defect are commonly covered with a layer of iron oxide or nonmetallic inclusions.

Deficient welds in welded tubing can often be identified visually once coverings of corrosion products or deposits are removed. The deficiency will be apparent as an intermittent or continuous opening or crevice that runs in a straight line down the tube wall.

Such defects in boiler tubes commonly result in stress rupture or fatigue-associated failures. In lower-temperature applications, these defects may induce pitting corrosion along the defect site.

Elimination

Generally, once construction is completed, there is no economical way of detecting specific manufacturing defects. If they exist, and are serious, their presence is generally revealed by failure of the defective component.

If failure of a component results from a manufacturing defect, it may be advisable to survey similar components for evidence of defectiveness. This usually requires the use of nondestructive testing techniques, especially ultrasonic testing.

Cautions

Thick-walled ruptures from overheating are sometimes incorrectly diagnosed in the field as material defects. Confirmation by metallographic examination may be required.

Related Problems

See also Chap. 2, "Long-Term Overheating," and Chap. 3, "Short-Term Overheating."

Figure 19.1 Curved defect originating on the internal surface of a seamless tube. This defect ran for 18 in. (45.7 cm) along the length of the tube. *(Courtesy of National Association of Corrosion Engineers.)*

CASE HISTORY 19.1

Industry:	Pulp and paper
Specimen Location:	Screen tube, recovery boiler
Specimen Orientation:	Vertical
Years in Service:	11
Water-Treatment Program:	Coordinated phosphate
Drum Pressure:	1200 psi (8.3 MPa)
Tube Specification:	2½ in. (6.3 cm) outer diameter
Fuel:	Black liquor

The longitudinal tube rupture apparent in Fig. 19.2 is 1½ in. (3.8 cm) long. Both visual and microstructural examinations reveal that the rupture occurred along a weld seam. Seam contours were clearly visible along the length of the tube.

Examination of cross sections taken at a distance from the through-wall rupture reveals that the unfused weld seam penetrates 40% of the tube-wall thickness, and is lined with dense iron oxide (Fig. 19.3). This is a weld-seam defect that occurred during tube manufacturing. An acid cleaning of the boiler caused the cavernous metal loss apparent near the surface in Fig. 19.3. External metal loss on the adjacent tube due to erosion from steam and water escaping from the through-wall rupture is apparent in Fig. 19.2.

Figure 19.2 Seam defect (top tube). External metal loss on the bottom tube is the result of erosion from mixed steam and water escaping through the rupture.

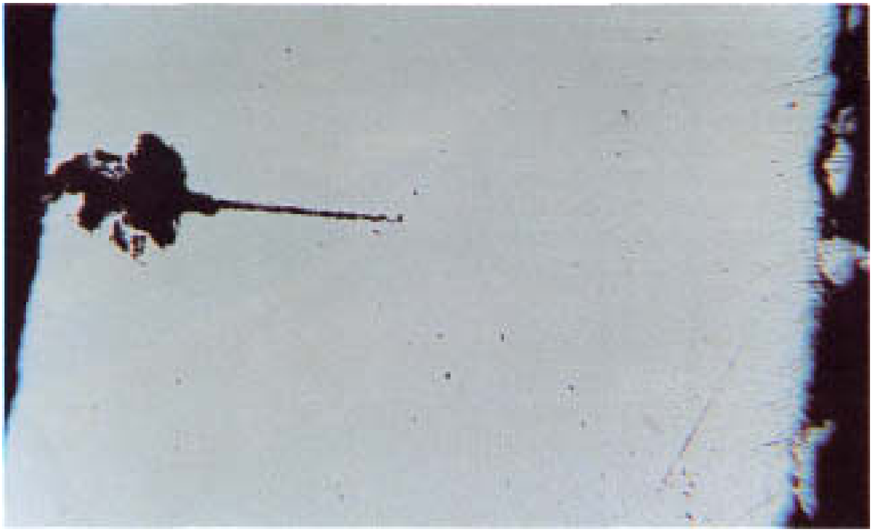

Figure 19.3 Cross-sectional view of weld-seam defect originating on the internal surface. Note enlargement of opening due to past acid cleaning of the boiler. (Magnification: 20X.)

CASE HISTORY 19.2

Industry:	Pulp and paper
Specimen Location:	Chill tube, power boiler, located in dead air space
Specimen Orientation:	Vertical
Years in Service:	25
Water-Treatment Program:	Phosphate
Drum Pressure:	900 psi (6.2 MPa)
Tube Specifications:	4 in. (10.2 cm) outer diameter

The massive failure illustrated in Fig. 19.4 occurred as the boiler was being brought on line. Drum pressure at the time of failure was 800 psi (5.5 MPa). An identical failure occurred a year earlier under the same conditions. The boiler is used intermittently and had been out of service for 5 months previous to this failure. The tube supplies a lower header in a waterwall.

Figure 19.5 illustrates the brittle rupture. Note the numerous parallel striations running along the fracture face.

Visual examinations of the internal surface revealed fissures along a welded seam aligned with the rupture. Microstructural examinations revealed that the rupture occurred along the weld seam. These examinations also disclosed deep fissures and pits along the seam resulting from exposure to acid during acid cleanings of the boiler.

Figure 19.4 Massive rupture of tube along a weld-seam defect.

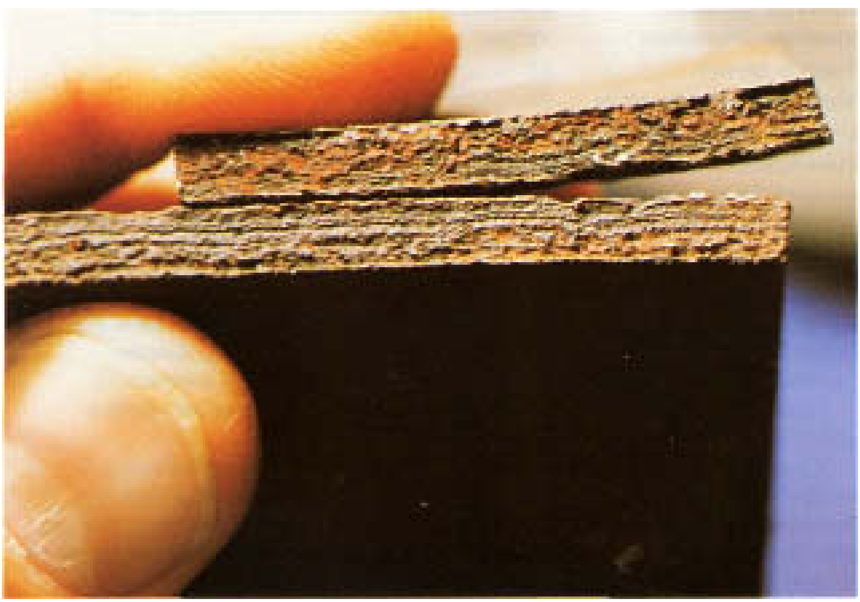

Figure 19.5 Edges of brittle rupture.

Apparently, the weld seam had not completely fused during tube fabrication. Acid collecting in the narrow crevice escaped neutralization. Consequently, when the boiler was restored to service following the acid cleaning, severe corrosion occurred along the seam, causing it to deepen. Eventually, stresses imposed by the cyclic operation of the boiler caused the crevice to grow by a corrosion-fatigue mechanism. When the crevice achieved a critical depth, fracture occurred through the remaining intact tube wall, which was incapable of supporting stresses imposed by internal pressure. Overheating had not occurred.

CASE HISTORY 19.3

Industry:	Utility
Specimen Location:	Secondary-superheater pendant
Specimen Orientation:	Vertical
Years in Service:	1
Water-Treatment Program:	Congruent control
Drum Pressure:	2500 psi (17.2 MPa)
Tube Specifications:	1¾ in. (4.4 cm) outer diameter, SA-213 T22, seamless tube
Fuel:	Coal

The failure illustrated in Fig. 19.6 is an 8-in.-long (20.3-cm-long), thick-walled fracture that originated on the internal surface (Fig. 19.1). Examination of the fracture face reveals a very smooth contour curving toward the external surface (Fig. 19.7). The extent of this smooth area is approximately 60 to 80% of the tube-wall thickness and runs 18 in. (45.7 cm) of the tube length. The fracture is covered with a very uniform layer of black iron oxide. The remaining 20 to 40% of the fracture surface adjacent to the external surface is irregular and lacks a distinct iron oxide covering.

Microstructural examinations revealed evidence of moderate overheating. Nonmetallic inclusions and the metal grains themselves are aligned along the contours of the smooth portion of the fracture.

This failure is a direct result of a manufacturing defect that extended for 60 to 80% of the original tube-wall thickness. Elevated stresses through the reduced tube-wall cross section, coupled with moderate overheating, caused final failure by stress rupture through the remaining intact tube wall. The defect appears to be an internal lap or seam, possibly associated with remnants of pipe (internal voids) in the steel ingot from which the tube was formed.

Rupture of the tube resulted in rapid, severe, localized wall thinning of adjacent tubes due to erosion from steam and water issuing from the rupture (see Case History 17.1). A second identical failure occurred in the superheater section 4 years later. It is remarkable that a tube with a defect of this magnitude could survive 5 years of service in a boiler of this pressure.

Figure 19.6 Failure along a massive manufacturing defect in the tube wall. *(Courtesy of National Association of Corrosion Engineers.)*

Figure 19.7 Smooth curved contour of defect. *(Courtesy of National Association of Corrosion Engineers.)*

CASE HISTORY 19.4

Industry:	Automotive
Specimen Location:	Steam line
Specimen Orientation:	Horizontal
Years in Service:	20
Water-Treatment Program:	Polymer
Drum Pressure:	210 psi (1.4 MPa), cyclic
Tube Specifications:	4½ in. (11.4 cm) outer diameter

The seam defect apparent in Fig. 19.8 required the replacement of a 25-ft (7.6-m) section of steam line. Ruptures in a similarly defective line had occurred a year earlier. A crack, which originated at the seam, penetrates the external surface for most of this 4-in. (10.2-cm) section.

Microstructural evaluations revealed decarburization of the metal, as well as the presence of iron nitride needles and nonmetallic inclusions in the weld-seam area. The through-wall crack followed the pathways of the nitride needles.

Figure 19.8 Seam defect in steam line.

The incompletely fused seam formed a narrow crevice that served as a stress-concentrating notch. Under the influence of cyclic pressure variations, corrosion-fatigue cracks propagated from the tip of the notch. The progress of these cracks was accelerated by the embrittling effect of the nitride needles present along the weld-seam zone. The combination of the diminished wall cross section resulting from an incompletely fused seam, the propagation of corrosion-fatigue cracks originating at the root of the open seam, and the presence of iron nitride needles resulted in a through-wall longitudinal failure of the line.