CASE STUDY

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Failure Analysis – An Overview with a Case Study

Krishnan Sivaraman*, Abhishek Singh

Larsen & Toubro Limited, Heavy Engineering IC, Powai Campus, Mumbai, Maharastra, India

Abstract

Failure analysis relies on collecting failed components for subsequent examination of the cause or causes of failure using a wide array of methods, especially microscopy and spectroscopy [1]. One of the important parameters in executing a failure analysis is properly observing each factor related to failed component and providing an unbiased conclusion and corrective action. The objective of failure analysis is to identify whether the failure has happened during service or during its manufacturing phase. The reason for failure would help to design and manufacture the component in an optimum way so as to ensure enhanced product life during service.

The paper covers basics of failure analysis, various failure modes, and failure analysis as a general engineering tool to improve product performance and failure prevention. In addition, this paper also covers a typical case study to explain the process methodology in detail.

Keywords: Case Study, Failure Analysis, Microscopy, Spectroscopy.

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INTRODUCTION

Failure analysis plays a vital role in establishing the cause of failures.[1] The analysis needs to be performed very systematically in order to identify the reason for failure and to establish preventive measures. The role of a competent design and metallurgical engineer is very crucial in the overall process to establish the cause of failure and to incorporate the learning in the product life cycle.

In general, failure can occur due to following reasons:

- Improper service conditions
- Not maintaining the component as required for its trouble-free operation
- Error in quality control and assurance
- Possible errors during assembly
- Errors happening while manufacturing
- Improper component design
- Error in a selection of material
- Faulty testing mechanism

Need for Performing Failure Analysis

The primary objective of performing failure analysis is to determine the reason for failure. The analysis is generally performed by a cross-functional team comprising of design, metallurgy, quality, process, and executive function. A substantial amount of data collected during the process makes the analysis more effective and robust. A very systematically performed failure analysis helps in identifying the failure mechanism and thereby institutionalize the preventive measures in place.

Corresponding Author: Krishnan Sivaraman, Larsen & Toubro Limited, Heavy Engineering IC, Powai Campus, Mumbai, India. E-mail: Krishnan.Sivaraman@larsentoubro.com

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Steps of a Failure Investigation

Following are the steps involved:

- Understand the purpose of the investigation
- Study the failure in detail
- Identification of all likely causes which might have led to failure
- Objective evaluation of each of the causes identified above
- Narrow down to the most likely reason for failure

The investigating team must have good know-how on the various failure mechanisms. This would help them to differentiate between available scenarios and then narrow down to the most probable one. The effectiveness of the analysis also depends upon the selection of suitable technique for evaluation and testing purpose.

Mode of Fracture

Following basic knowledge is required for the investigator to analyze the failure mode.

There are various modes of fracture involved in the failure. Each fracture mode is characterized by some specific feature. Some typical features observed during different fracture modes are captured in Table.1.

Table 1: Fracture mechanisms and their fracture surface characteristics[2]

Mode of Fracture	*Typical fracture surface Characteristics*
Ductile	Cup and Cone, Dimples, Dull Surface, Inclusion at dimple bottom (refer Figure 1)
Brittle Inter-granular	Shiny, Grain Boundary cracking
Brittle Trans-granular	Shiny, Cleavage fractures, Flat (refer Figure 2)
Fatigue	Beach marks, Striations, Initiation sites, Propagation area, Zone of final fracture (refer Figure 3)

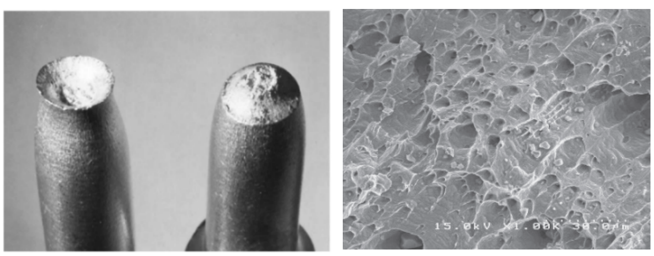

Figure 1: Photograph showing ductile mode of fracture

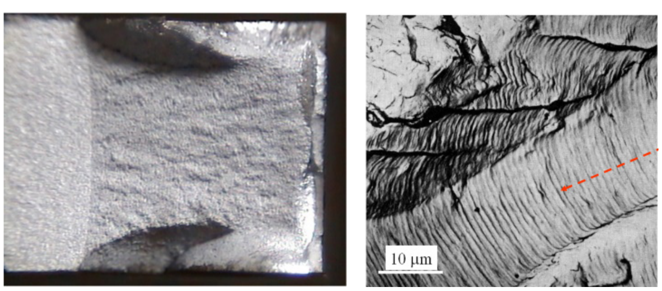

Figure 2: Photograph showing brittle mode of fracture

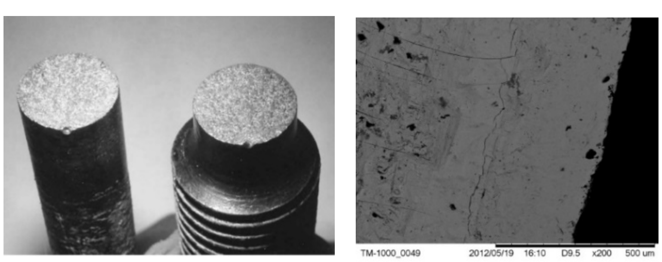

Figure 3: Photograph showing fatigue mode of fracture

Table 2: Commonly used non-destructive tests (NDTs) and their capabilities in detecting defects[3]

Ndt method	*Description/capabilities*
Radiography	Measures differences in radiation absorption. Best suited for detection of volumetric defects Inclusions, porosity, cracks
Ultrasonic	Uses high frequency sonar to find subsurface defects. Best suited for detection of planar defects Inclusions, porosity, thickness of material, position of defects
Dye penetrant	Uses a dye to penetrate open defect and developer to reveal Surface cracks and porosity
Magnetic particle	Uses a magnetic field and iron powder to locate surface and sub surface defects. Suitable for ferromagnetic materials only Surface defects
Eddy current	Based on magnetic induction. Cracks, porosity, and inclusions

Typical tests Carried out to Analyze the Reason for Failure

- Visual Examination - Visual examination is a valuable tool for the investigator to examine the fracture surfaces in detail and try to identify the mode of fracture (brittle, ductile, fatigue, etc.), points of initiation, the direction of propagation, etc.
- Non-Destructive Examination (NDE) – This tool helps the investigator to examine the parts without causing permanent damage. Several types of NDT are carried out during failure analysis, their capabilities are captured in Table 2.
- Macroscopic Examination - The macroscopic examination is best performed when cataloging the samples; however, the investigator will often want to return to examine the part in more detail once other evidence is gathered.
- Chemical Analysis - Chemical analysis is done on the bulk of the material to confirm the material composition. Many techniques are available to check the composition, and the choice of suitable technique often depends on accessibility and sample type.
- Mechanical Testing – Mechanical testing checks whether the material conforms to the standards. There are many types of mechanical testing that can be performed like tensile tests, impact tests etc.
- Metallographic examination using optical microscopy - Metallographic examination involves the sectioning of

samples to examine the microstructure. The sections that are selected for examination are dependent on the type of piece and the mode of fracture. Sections from the sample should be taken in different planes so that any differences in the microstructure can be seen.

- Hardness - Hardness testing is a very common tool used in failure analysis because of its relative simplicity and low cost. Macro hardness helps to determine material properties. However, Microhardness measurements are helpful in determining property variations within the material.
- Material characterization is performed using instruments like Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS), Microprobe & X-ray Diffraction Analysis (XRD) etc.

Case Study

Various steps involved in a failure analysis are explained here through a case study on "Failure of Stainless-Steel tube of SS304 during Pneumatic Testing".

Introduction

Stainless steel U-tubes, SA 688M TP 304, were stored in wooden boxes for almost one year. The tube details are as mentioned below:

When these tubes were taken for fabrication, during pneumatic testing, few tubes were found leaking. Two leaking tubes were chosen for further study & analysis.

Investigation

Following tests were performed as part of investigation:

Tube Outer Diameter	Tube Thickness	Total Number of Tubes
19.0mm	0.9mm	700

- Visual examination
- Metallographic examination
- Hardness test
- Chemical analysis
- Scanning Electron Microscope (SEM)
- Energy Dispersive Spectroscopy (EDS)

Visual examination of tubes showed brown rust marks and deposits at the location of failure on outer surface of the tube (Refer Figure 4). On cleaning, some pit marks were visible on the tube's outer surface (Refer Figure 5). However, tube inside surface did not show any deterioration when examined by boroscopy.

Samples were extracted from defective tubes for detailed investigation.

Metallography examination of both the tube samples revealed normal austenitic step structure without any carbide precipitates at grain boundaries (Refer to Figure 6 ot 7). Corroded portions of the tube outside surface revealed pits on examination at higher magnification. After etching, pits were observed to be in weld (long seam of a tube) as well as base metal region.

A hardness test was performed on a longitudinal cut section of a tube from the inside. Hardness values were in the range of 74-77 HRB, which met the specification requirement of 90HRB maximum.

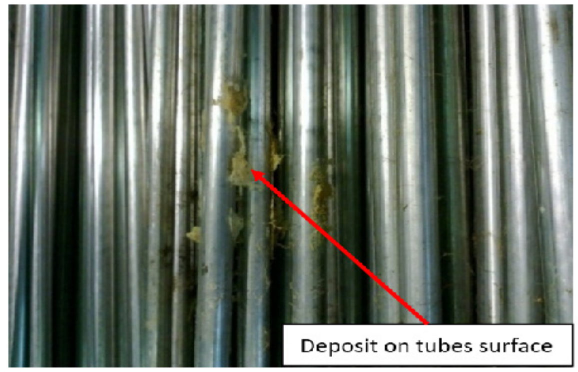

Figure 4: Deposits observed on outer surface of tubes

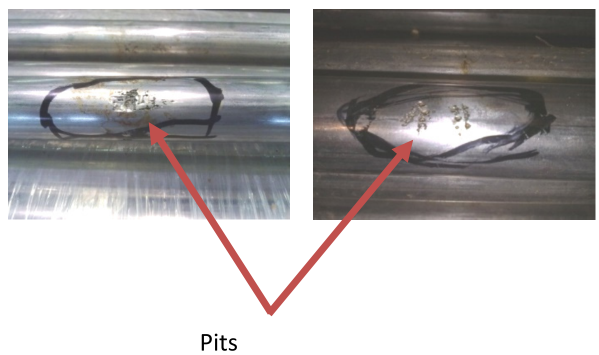

Figure 5: Tube samples showing pit marks on outer surface

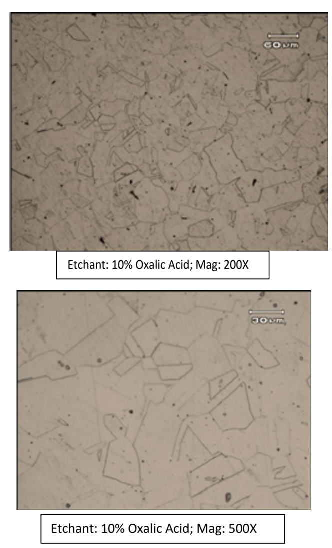

Figure 6: Tube No. 1- Austenitic step structure with no evidence of sensitization

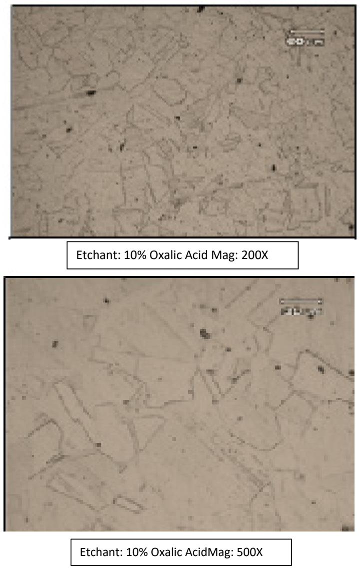

Figure 7: Tube No. 2- Austenitic step structure with no evidence of sensitization

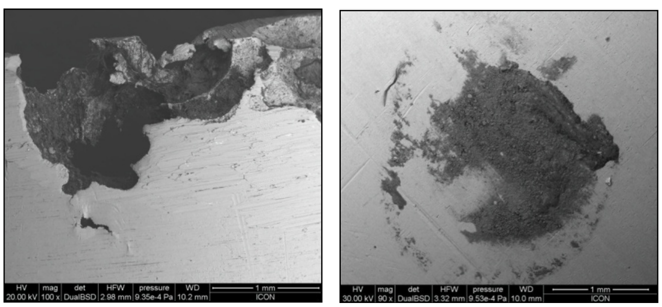

Figure 8: SEM photographs of pits on outer surface.

Table 3: Chemical Analysis of tube

Element	*Chemical analysis of tube by spectroscopy in %*	*Material specification requirement as per SA 688M in %*
%C	0.023	0.08 max.
%S	0.014	0.030 max.
%P	0.027	0.040 max.
%Mn	1.47	2.0 max.
%Si	0.48	0.75 max.
%Cr	18.37	18-20
%Ni	8.06	8-11

The tube sample was subjected to chemical analysis by spectroscopy, and results of the same are tabulated in Table 3.

Chemical composition of the tubes was meeting the specification requirements.

SEM analysis revealed pit marks on outer surface of tube (Refer Figure 8)

EDS analysis was carried out at these pits, which revealed presence of high percentage of chloride in comparison to other un-affected locations (Refer Figure 9 to 10). In EDS analysis, Chloride content found to be 0.73% (7300 ppm) & Cr content found to be 1.90%. The generally recommended maximum chloride level for SS 304 is only 200 ppm. However, free chloride concentrations as little as 25 ppm can have a detrimental effect on material.[4]

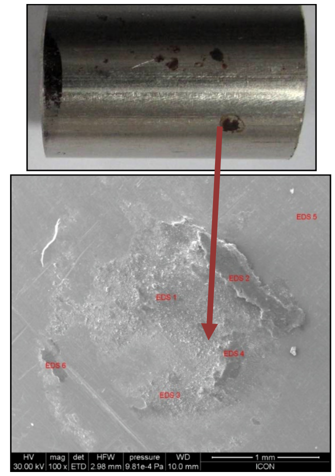

Figure 9: Location of EDS analysis on outer surface of tube at pit

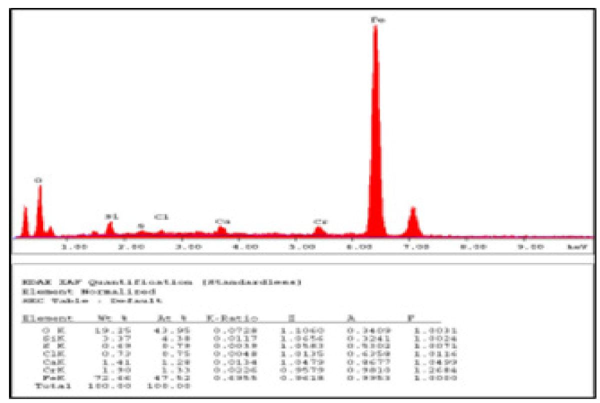

Figure 10: Graph of EDS analysis at corroded location

CONCLUSION

Based on investigation performed on the tube samples, conclusion could be drawn that, pitting corrosion[4] has caused the leakage of tubes. Pitting marks were visible only on outer surface of the tubes and no defects were observed on the inside surface. This pitting corrosion is due to high chloride content[5] at localized points in view of improper storage of tube bundle causing seepage of water.

SUMMARY

Comprehensive failure analysis involves a very systematic approach, collection and evaluation of available data, a very clear know-howof the failure mechanism, and narrowing down to the most likely reason for failure. The choice of tool to be used while performing an investigation depends on a particular case & the nature of failure.

Once the reason for failure is established, necessary changes can be incorporated in the product, and thereby prevent repeated failures.

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