SYSTEMATIC INVESTIGATION OF FAILURE ANALYSIS ON A STEAM TRAP BYPASS TUBE IN A COALFIRED POWER PLANT

MOHD ARIF ANUAR MOHD SALLEH

A project report submitted in partial fulfillment of the requirements for the award of Masters Degree in Mechanical Engineering

Faculty of Mechanical and Manufacturing
Tun Hussein Onn University of Malaysia

NOVEMBER 2007

ACKNOWLEDGMENT

In the name of Allah, the most gracious, the most merciful

Firstly, with the highest praise to Allah that I managed to complete this project successfully. I would like to express my heartiest thankful to my supervisors, Associate Professor Dr-Ing Darwin Sebayang and Dr. Syahril D.I.C for their continuing guidance, valuable advices, ideas, support and encouragement in completing this project successfully.

Besides that, I would like to express my special thanks to the lecturers, technicians of mechanical laboratories and to those who involved and giving sincere cooperation during completing this project.

I would also like to express my special thanks to my dad Prof. Dato' Dr. Mohd Salleh Hj. Din, my mum Prof. Madya Datin Maziah Onn, and also to my siblings that inspired me and always supported me through this project. Besides that, I would also like to express my special thanks to my friends and Noor Farhani Mohd Alui.

ABSTRACT

A steam trap bypass tube in a power plant was totally fractured. The aim of this study is to examine the evidence presented by the steam trap bypass tube failure, determining the failure mechanism, determining the root cause of the failure and to recommend appropriate corrective actions. The power plant is a coal fired power plant with its normal operation temperature of 540°C. This study consists of failure mode inventory collection of the steam trap bypass tube failure, collection of background information about the process, component function and operating conditions. Detailed investigation carried out by visual examination, nondestructive testing (NDT), metallurgical testing which consists of microstructure examination, chemical testing and mechanical testing. Optical Microscopy (OM), Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS), Glow Discharge Spectrometer (GDS) and Energy Dispersive X-ray Diffraction (XRD) experiments were used throughout the investigation on the sample obtained. From the evidence with considering the contribution factors such as temperature, pressure and environment, a fault analysis was made and it can be concluded that the cause of failure to the steam trap bypass is due to multi causes which consists of creep failure and hydrogen damage. The root cause of high temperature creep and hydrogen damage which occurred at the steam trap bypass tube is due to material properties that are inadequate for the actual operating conditions of a steam trap bypass tube which is not according to the specification. The material must be actually ASTM SA-335-P22 (2.25Cr-1Mo) with 490MPa minimum tensile strength and 320MPa minimum yield strength. However from the investigation found that the material used was ASTM SA-192 (low strength carbon steel) with 324MPa minimum tensile strength and 180MPa minimum yield strength.

ABSTRAK

Sebatang paip perangkap stim pada sebuah stesen janakuasa didapati telah musnah sepenuhnya. Tujuan kajian ini adalah untuk menkaji kesan yang diperlihatkan dari paip yang pecah, mengetahui mekanisma kegagalan, mengetahui punca utama kegagalan serta memberi cadangan kaedah supaya kegagalan tidak akan berulang pada masa hadapan. Stesen janakuasa tersebut adalah dari jenis stesen janakuasa yang menggunakan arang batu sebagai bahan bakar dan beroperasi pada suhu 540°C. Kajian ini terdiri daripada penemuan mode kegagalan, pengumpulan maklumat latar belakang prosess, fungsi komponen serta keadaan beroperasi. Kajian dilakukan dengan melakukan pemerhatian secara visual, ujian tanpa musnah (NDT), ujian metalurgi yang terdiri daripada pemerhatian mikrostruktur, ujian kimia serta ujian mekanikal. Optical Microscopy (OM), Scanning Electron Microscopy (SEM) gabungan Energy Dispersive X-ray Spectroscopy (EDS), Glow Discharge Spectrometer (GDS) dan Energy Dispersive X-ray Diffraction (XRD) eksperimen telah digunakan sepanjang melakukan kajian pada sample yang diperolehi. Hasil dari penemuan dengan mengambil kira faktor-faktor seperti suhu, tekanan serta keadaan sekeliling, satu analisis punca kegagalan dilakukan dimana punca kegagalan adalah disebabkan dwi punca yang terdiri daripada rayapan bersuhu tinggi serta kemusnahan hydrogen. Punca utama kegagalan pada pipe perangkap stim ini adalah disebabkan sifat bahan yang digunakan adalah tidak bersesuaian dengan keadaan operasi dimana bahan pipe yang digunakan tidak mengikut spesifikasi. Bahan yang digunakan pada pipe perangkap stim yang musnah haruslah ASTM SA-335-P22 (2.25Cr-1Mo) dengan 490MPa kekuatan tegangan minimum dan 320MPa kekuatan alah minimum. Namun demikian setelah penyelidikan, bahan pada pipe perangkap stim yang digunakan adalah ASTM SA-192 (keluli karbon rendah) dengan 324MPa kekuatan tegangan minimum dan 180MPa kekuatan alah minimum.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

°C	-	Degrees Celcius
°F	-	Degrees Farenheit
%	-	Percentage
Ŋ_c	-	Grains cut by the circumference
Ŋ_i	-	Grains in area
M	-	Magnification
N_A	-	Number of grains per unit area
N_V	-	Number of grains contained in unit volume
HV	-	Vickers Hardness
σ_y	-	Yield strength
c	-	Constant
σ_{UTS}	-	Ultimate Tensile Strength
e	-	Elongation
σ	-	Stress

LIST OF ABBREVIATIONS

SEM	-	Scanning Electron Microscopy
OM	-	Optical Microscope
EDS	-	Energy Dispersive X-ray Spectroscopy
GDS	-	Glow Discharge Spectrometer
XRD	-	Energy Dispersive X-ray Diffraction
EDM	-	Electrodischarge Machining
NDT	-	Non Destructive Testing
OD	-	Outside Diameter
ID	-	Inside Diameter
ASTM	-	American Society for Testing Materials
UTS	-	Ultimate Tensile Strength

LIST OF APPENDIX

CHAPTER I

INTRODUCTION

In a power plant industry, failures usually occur on tubes and pipelines. Establishing the causes of failures provides information of improvements in design, operating procedures and the use of components. Failure analysis is an engineering approach to determine how and why an equipment or component has failed. Failure occurs when it does not meet its requirements. Failure analysis can also be defined as an investigation to determine the underlying reasons for the nonconformance to system requirements and is performed to identify nonconformance root causes and to recommend appropriate corrective actions [1].

A failure investigation and subsequence analysis should determine the primary cause of a failure, and based on the determination, corrective action should be initiated that will prevent similar failures. Although the sequence is subject to variation, depending upon the nature of a specific failure, the principal stages that comprise the investigation and analysis of failure is firstly the collection of background data and selection of samples [2]. Preliminary examination of the failed part which includes visual examination and record keeping will be the next stage of investigation. Nondestructive testing and mechanical testing that includes hardness test can also be done as part of the investigation. The next stage is the selection, identification, preservation or cleaning of all specimens. Macroscopic examination and analysis is the next stage where fracture surface, secondary cracks and other surface phenomena will be identified. After the macroscopic examination, microscopic examination and analysis is the next stage. Selection and preparation of metallographic sections will need to be done thus the examination and analysis of metallographic sections. From the examinations, failure mechanism will be determined. For further investigation, chemical analysis which includes determining the bulk, local, surface corrosion products, deposit or coatings will be done. From the results, analysis of fracture mechanics will then be determined. Testing under simulated service conditions can be done for further analysis. The final stage is the analysis of all the evidence, formulation of conclusion and writing the report [2].

1.1 Statement of Problem

Cut-off a failed steam trap bypass tube of a coal-fired power plant was received. The tube is said to be made of a TU10CD9-10 (tube specification) which corresponds to ASTM SA335 P22. The outside diameter (OD) of the tube is 63.5 mm and the inside tube diameter (ID) is 53.34 mm. The received steam trap bypass tube was completely fractured and this study is to identify the root causes and to recommend appropriate corrective actions due to the failure. Figure 1.1 shows the insulated steam trap bypass tube in actual process and figure 1.2 shows the pieces of fractured steam trap bypass tube.

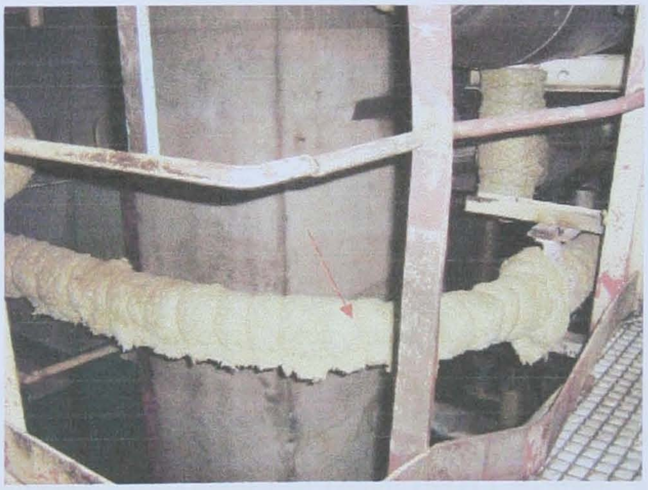

Figure 1.1: Insulated steam trap bypass tube in actual process.

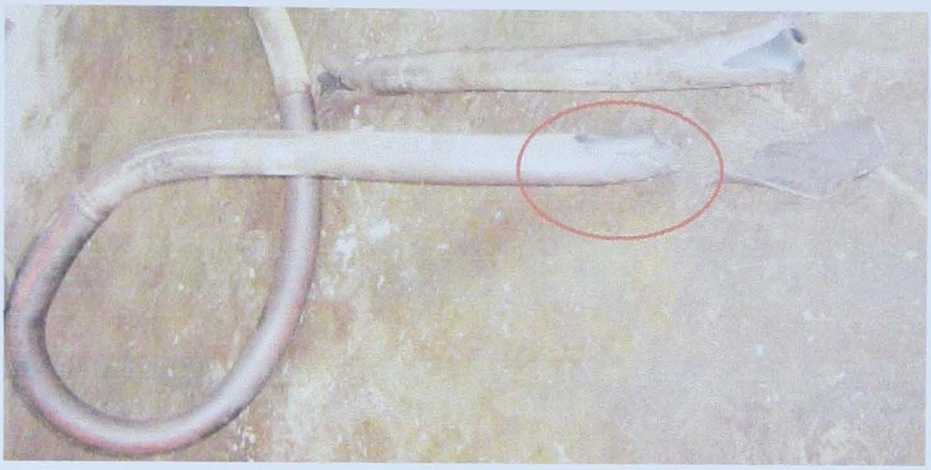

Figure 1.2: Fractured steam trap bypass tube (in circle indicates picture of sample received).

1.2 Objective of Study

There are three primary objectives in this study, the first objective is to examine the evidence presented by the steam trap bypass tube failure and determining the failure mechanism. The second objective is to determine the root cause of the failure. The third objective is to recommend appropriate corrective actions to overcome the problem.

1.3 Scope of Study

The study involves collection of failure mode inventory of the steam trap bypass tube failure. This study also involves collection of background information about the process, component function, operating conditions and failure event sequence. Detailed investigation carried out by Non Destructive Testing (NDT), microstructure examination using Optical Microscopy (OM), Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS), Glow Discharge Spectrometer (GDS) and

Energy Dispersive X-ray Diffraction (XRD) testing on the sample will be done. From these results, analysis of the result will be done to determine the root cause of the steam trap bypass tube failure.

CHAPTER II

LITERATURE REVIEW

Fracture and failure is a natural and frequent phenomenon, the consequences of which are both positive and negative. Fracture mechanics has gained a primary role in the analysis of the mechanical behavior of materials. The fundamental aspect of elasticity and plasticity being already clarified, the research cutting edge is focusing on the several damage phenomenons either smeared or discrete occurring with a decrease of the loading capacity when the structural deformation increases [24]. These loading stage represents the pre-collapse condition and is investigated today both experimentally and numerically. During such an unstable and final process, the elementary failure mechanisms may interact such as brittle fracture propagation, plastic deformation, fatigue, creep and instability of the equilibrium.

Any attempt to describe and to investigate the transient period of the failure process, according to the actual sequence of the critical events is therefore extremely a significant. As long as failures of industrial components are approached and investigated in a systematic and consistent manner, it will be able to go back to the true causes and thus prevent similar recurrence.

Since long time ago, failure investigations and analysis of case studies had been done at different types of areas, components and different operational background such as on weldment parts, pressure components, process engineering and petrochemical components, machinery and mechanical components, power engines, chemical and food plant, civil and transportation and also on steam units according to the failure occurred.

From previous failure investigations done by many researchers and investigators, the failure investigation on a steam trap bypass tube has not been done and reported. Since then, failure modes of previous failure investigations on different parts which are similar to the steam trap bypass tube background information which includes the working medium, temperature, pressure and type of material were studied. One of the examples of previous failure investigations done by researches and investigators used as failure modes is failure on a primary superheater [25]. The service life of tube is 7 years before failure. The steam temperature & pressure of tube are and 450°C and 140 kg/cm^2 respectively. The tube has OD 63.5 mm and ID 5.5 mm. The tubes are located horizontally with flue gas passes vertically. Upon SEM examination conducted as in figure 2.1 (a), it revealed presence of inter-granular cracks and presence of numerous creep cavities at grain boundary. Presence of micro-cracks are observed more towards outer surface and near by crack region. Severity of cracks and cavity reduces when we move away from the main crack. From microstructure examination as shown in figure 2.1(b), the crack displayed inter-granular nature of propagation with many small parallel cracks adjacent to main crack is observed. This magnification was done using a Leco Image Analyzer at 300X. In present case the failure of tube seems to have occurred due to long term over- heating, above allowable design temperature, could be due to higher velocity of flue gas at this region or impingement of flue gases on tube surface facing flue gas or improper steam flow.

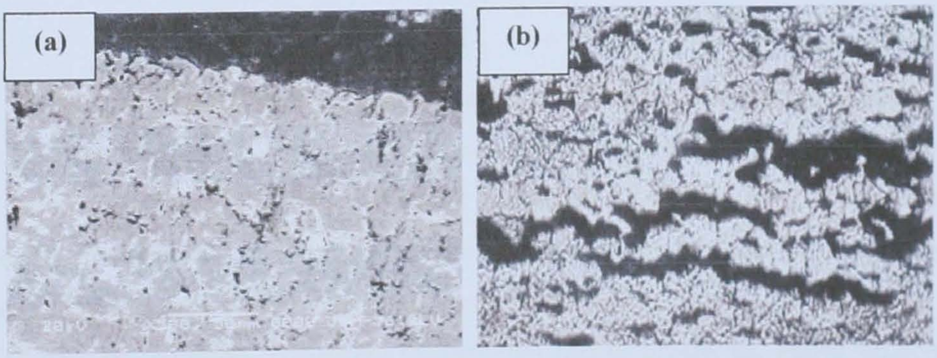

Figure 2.1: (a) Inter-granular cracks and presence of numerous creep cavities at grain boundary (b) Inter-granular nature of propagation with many small parallel cracks.

Failure investigation was also done on a furnace tube failure [25]. The failure occurred in a bottom fired furnace tube with experienced service of 14 months against the normal life of 6 to 7 years. The tube is 25 Cr/35 Ni. The average tube metal temperature remains between 1000°C to 1100°C temperatures. As per the manufacturer data, these tubes are designed for 1150°C. The pressure inside the tube is 1 kg/cm^2. SEM analysis conducted revealed a progressive nature of fracture especially towards OD side shown in figure 2.2 (a). However, majority evidences on fracture surface were masked under heavy scaling, which is generally expected under such service. From microstructure examination (figure 2.2 (b)), the crack is associated with carburizing more so at outer surface with decreasing the depth of carburizing towards ID which is another important evidence of crack originating from outer diameter and progressing towards ID. This magnification was done using a Leco Image Analyser at 300X. In present case the failure of tube has occurred due to localized overheating, which reduced ductility and failed under operational vibrations.

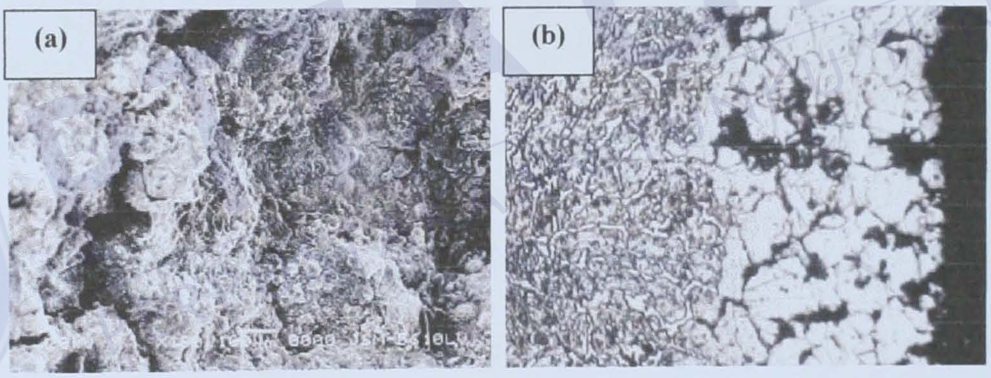

Figure 2.2: (a) Progressive nature of fracture (b) Crack is associated with carburizing more at outer surface.

Another example of failure investigation done is failure investigation on a sulfuric and concentration plant piping [25]. In a sulfuric acid concentration plant, as a part of process, condensate is chilled in a heat exchanger. The line, which is connected from heat exchanger (E08-3) to vacuum pump, one elbow was reported to have leaked and needed replacement. Severe corrosion was reported inside the replaced pipeline within 10 days of operation. The extent of corrosion was so severe that entire replaced pipeline reduced to paper thickness with punctures. The pipeline is operating with 1 to

2% H_2SO_4, 0.5% HNO_2 and 0.6 to 1.0 % HNO_3 at 10 to 20°C temperatures. Low magnification examination was done by the failure Analysis and Investigation team to find out the corrosion characteristics. Internal surface of pipe, weld and elbow showed severe corrosion on pipe. The close-up view of corroded surface inside the pipe showed effect of general corrosion and flow pattern (figure 2.3 (a)). Leakages observed in the form of openings between weld and pipe. From microstructure examination, uniform dissolution at ID is observed under microstructure examination at a magnification of 300X as shown in figure 2.3 (b). The fluctuation in nitric acid concentration did not allow stabilizing passivity on newly fabricated pipeline resulted into severe corrosion.

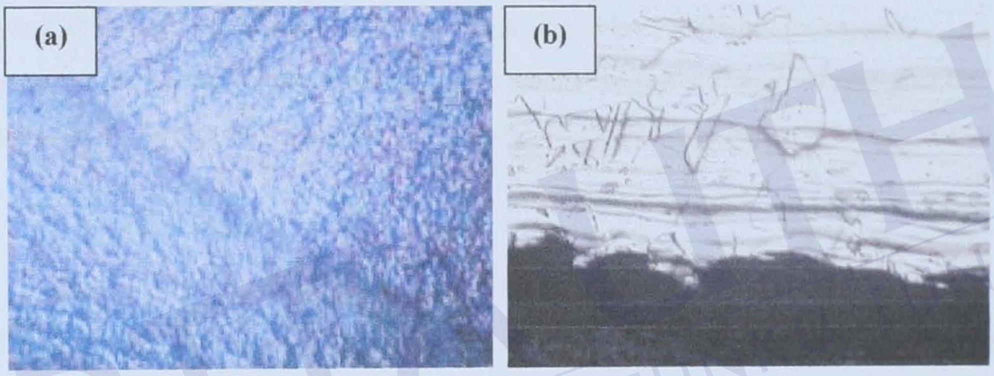

Figure 2.3: (a) Effect of general corrosion and flow pattern
(b) Uniform dissolution at ID.

In this study, it consists of systematic investigation of failure analysis on a steam trap bypass tube. Since failure investigations has not been done on a steam trap bypass tube, this study is important to produce information on steam trap bypass failure modes, information and also the failure mechanisms that may occur on a steam trap bypass tube. These results will be able to give failure experience information's and thus to prevent similar recurrence on a steam trap bypass tube.

2.1 Steam Trap Function and Operation

In most plants, steam is produced in a power plant with a boiler. This allows the majority of heat energy to be produced in a central location. The steam is then piped throughout the facility via steam lines to locations where heat energy is needed. In many cities, steam may be purchased from local utilities. Regardless of the source, steam is expensive and preventable losses are unacceptable.

Steam is an odorless, colorless, tasteless gas which forms when water is heated above 212°F (100°C). In a pressurized system, steam is capable of storing and transporting large quantities of energy. Once steam has formed, more energy can be introduced by further heating. This causes both its temperature and pressure to rise.

Once steam leaves the boiler, it begins to lose energy and cool. As its temperature falls, the steam condenses back into water. Failure to remove condensate from the steam system sets up a vicious cycle [3]. From the typical normal power plant layout by P.K Nag as shown in figure 2.4, the steam pressure that enters high pressure heaters is at 50 bar and 10 bar. The steam pressure that enters low pressure heaters is at 3 bar and 1.5 bar. Steam traps are normally situated after the heaters to remove the condensate from the steam. Referring to the highest pressure entering a heater with 50 bar, the temperature of steam is in the range of 520°C-530°C. For this case failure analysis case study, since the actual pressure and temperature was not obtained, it is assumed with the maximum values of pressure and temperature. The steam trap is situated at the highest pressure 50 bar and temperature in the range of 520°C-530°C.

REFERENCES

1. Charlie R. Brooks (1993). "Metallurgical Failure Analysis." McGraw-Hill Companies.

2. Raymond F. Decker (1990). "Metals Handbook-Ninth Edition: Failure Analysis and Prevention." Ohio: American Society For Metals.

3. L.G Northcroft (1962). "Steam Trapping and Condensate Removal-E.E.U.A Handbook No. 8." London: Constable and Company Ltd.

4. R. Viswanathan (1995). "Damage Mechanisms and Life Assessment of High temperature Components." Ohio: ASM International.

5. V.Bafna, P.Haribhakti (2004). "Investigating Material and Component Failure." India: TCR Engineering Services.

6. R.K Dayal, N. Parvathavarthini (2003). "Hydrogen Embrittlement in Power Plant Steels." India: Indira Gandhi Centre for Atomic Research.

7. J.Woodtli, R. Kieselbach (1999). "Damage due to Hydrogen Embrittlement and Stress Corrosion Cracking." Dubensorf: EMPA.

8. N.Eliaz (2000). "Characteristic of Hydrogen Embrittlement in High Strength Steels." Cambridge, USA: Massachusetts Institute of Technology.

9. J.P Hirth (1985). "Theories of Hydrogen Induced Cracking of Steels." Ohio: Department of Metallurgical Engineering, Ohio State University.

10. M. Eyckmans (1999). "Hydrogen Damage in Belgian Utility Boilers." United Kingdom: Engineering Materials Advisory Services Ltd,

11. Mars G. Fontana (1987). "Corrosion Engineering." Singapore: McGraw-Hill International.

12. D. Hardie, E.A. Charles, A.H. Lopez (2006). "Hydrogen embrittlement of high strength pipeline steels." United Kingdom: Corrosion Research Centre, University of Newcastle upon Tyne.

13. J. M. Sarvar and J. M. Tanzosh (2003). "Steam oxidation testing of candidate Ultrasupercritical Boiler Materials." USA.

14. I. G. Wright and B. A. Pint (2000). "An Assessment of the High Temperature Oxidation Behavior of Fe-Cr Steel in Water Vapor and Steam." NACE Corrosion.

15. G. Das, S. G. Chowdhury, A. K. Ray,S. Das, and D. K. Bhattacharaya (2002). "Failure of a Superheater Tube." India: Engineering Failure Analysis.

16. Salustiano D.R.P (2006). "Failure Analysis of a Superheater Tube of a Coal-fired Power Plant" Tun Hussein Onn University of Malaysia: Master's Thesis.

17. Anil Kumar Sinha (2003). "Physical Metallurgy Handbook." USA: McGraw-Hill.

18. R. W. Bryers (1996). "Fireside Slagging, Fouling, and High-Temperature Corrosion of Heat-Transfer Surface due to Impurities in Steam-Raising Fuels Volume 22." Copyright Elsevier Science.

19. Frederick G. Hammit (1990). "Failure Analysis and Prevention-Liquid Erosion Failures." Ohio: Metal Handbook Ninth Edition, ASM.

20. W.G Ashbaugh (1990). "Failure Analysis and Prevention-Corrosion Failures." Ohio: Metal Handbook Ninth Edition, ASM.

21. Ralph M. Davidson (1987). "ASM Handbook-Corrosion (Hydrogen Damage)." Ohio: ASM International.

22. Bruce L. Bramfitt (2006). "Mechanical Engineer's Handbook-Carbon and Alloy Steels." John Wiley & Sons, New Jersey.

23. Gordon W. Powell (1990). "Failure Analysis and Prevention-Ductile and Brittle Fractures." Ohio: Metal Handbook Ninth Edition, ASM.

24. V. Bicego, A. Nitta, J.W.H. Price, R. Viswanathan (1999). "Case Histories on Integrity and Failures in Industries." United Kingdom: Engineering Materials Advisory Services LTD.

25. V. Bafhna and P. Haribhakti (2000). "Failure Analysis and Engineering Services." India: TCR Engineering Services.

26. A.K Das (1996). "Metallurgy of Failure Analysis." New Delhi: Tata McGraw-Hill Publishing Company Limited.

27. Arlan O. Benscoter (1998). "Carbon and Alloy Steels-Metallography and Microstructures ASM Handbook Volume 9." Ohio: ASM International.

28. Kalpakjian, S. (1997). "Manufacturing Processes for Engineering Materials." Addisson Wesley.

29. M. Zhou, S. J. Hu, H. Zhang (2000). "Critical Specimen Sizes for Tensile-Shear Testing of Steel Sheets." Department of Mechanical Engineering and Applied Mechanics, University of Michigan Ann Arbor.

30. P.K Nag (1999). "Power Plant Engineering." New Delhi: Tata McGraw-Hill Publishing Company Limited.

31. Robert C. Juvinall, Kurt M. Marshek (2006). "Fundamentals of Machine Component Design." New Jersey: John Wiley & Sons.

32. D. Herlach, C. Kottler, T. Wider, K. Maier (2000). "Hydrogen Embrittlement of Metals." Physica B.

33. D E. Herms, J.M. Olive, M. Puiggali (1999). "Hydrogen Embrittlement of 316L Type Stainless Steel." Materials Science and Engineering.

34. H. Kamoutsi, G.N. Haidemenopoulos, V. Bontozoglou, S. Pantelakis (2006). "Corrosion-induced Hydrogen Embrittlement in Aluminum Alloy 2024." Corrosion Science.

35. G. Bertolino, G. Meyer, J. Perez Ipin (2002). "Degradation of the Mechanical Properties of Zircaloy-4 Due to Hydrogen Embrittlement." Journal of Alloys and Compounds.

36. F. de Kazinczy (1954). "A Theory of Hydrogen Embrittlement" Journal of the Iron and Steel Institute.