Methodology for Investing Failures of Turbine Blade

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***Abstract*— Turbine blades are made of super-alloys with different cooling methods such as internal air channels, boundary layer cooling and thermal barrier coatings (TBC) to withstand high temperature of hot gases. In 1940, the development of super-alloys and new production methods in subsequent years increases the capability of turbine blades to withstand high temperatures. Modern turbine blades are manufactured mainly by Ni-based super-alloys.Turbine blades are subjected to very strenuous environments inside a gas turbine. Turbine Blades of a gas turbine engine are very prone to damage from flying debris; moreover they also sustain thermal stresses and local overheating on their surface of gases that are coming out from combustion chambers. They face high temperatures, high stresses, and a potentially high vibration environment inside turbine. All these factors can lead to blade failure, resulting in catastrophic failure of turbine. In this research work various methodologies/ techniques have been discussed, which are employed to investigate the failure in turbine blade.**

***Key words:* Fractography, Metallography, Scanning electron microscopy, X-ray diffraction technique**

I. INTRODUCTION

Gas turbine converts natural gas or other liquid fuels to mechanical energy. This energy then drives a generator that produces electrical energy. The first commercially used gas turbine for electric power generation was installed in 1949 at Belle Isle Station, Oklahoma, USA by a team consists of Bruce Buckland known as "Mr. Gas Turbine", Neal Starkey (GT Control Genius), Arne Loft (*Sharma, 2015 [1]*). Due to increase in generating capacity and operating pressure of individual utility units, various new methods have been employed to increase the efficiency of turbines. Recent methods include thin and highly twisted design of turbine blades with low aspect ratio, which results in high levels of vibratory stresses and forces the designers to use higher strength materials. Turbine blades are subjected to very strenuous environments inside a gas turbine. They face high temperatures, high stresses, and a potentially high vibration environment. All these factors can lead to blade failure, resulting in catastrophic failure of turbine. The turbine blade failure problems accounting around 42 percent of the total failures in turbines (*Allianz, 1978 [2]*). The factors which predominantly influence the blade life are High cycle fatigue, Low cycle fatigue, Fretting fatigue, High temperature oxidation, Sulphidation and Corrosion. In this research work the methodologies, which are employed to investigate the failure in turbine blade have been discussed and illustrated.

II. METHODOLOGY FOR INVESTING FAILURE OF TURBINE BLADE

Failure analysis conducted on the blade cracks consists of characterization of blade surfaces (e.g. pits, erosion, oxidation etc.), fractography of the crack or fractured surfaces and metallography. All these methods are quite significant for monitoring the conditions of a turbine blade.

III. FRACTOGRAPHY

Fractography is a technique to determine the cause of failure by studying the characteristics of a fractured surface. The word fractography consists of two words, fracto from the Latin word *fractus*, meaning fracture and graphy derived from Greek term *grapho*, meaning descriptive treatment.This technique is introduced by Carl A. Zapffe in 1944 (*Zapffe et al., 1945 [3]*).The purpose of fractography is to analyze the fracture features and also to relate the topography of the fracture surface to the cause and basic mechanism of fracture (*McCall, 1972 [4,5]).* Fractography technique has revealed direction of crack propagation, material defects, environment interaction, fracture origin, failure mechanism and nature of stresses. The steps followed in fractographic analysis are preservation, cutting of fracture, cleaning of fracture, visual inspection and electron fractography.

3.1 PRESERVATION

Fracture surfaces are fragile and subject to mechanical and environmental (chemical) damage, which can destroy microstructural features. Consequently, fracture specimens must be carefully handled during all stages of analysis. Chemical or mechanical damage of the fracture surface can occur during or after the fracture event.

Chemical damage of the fracture surface that occurs during the fracture event is the result of environmental conditions. If the environment adjacent to an advancing crack front is corrosive to the base metal, the resultant fracture surface in contact with the environment will be chemically damaged. Humid air is considered to be aggressive to most iron-base alloys and will cause oxidation. Touching a fracture surface with the fingers will introduce moisture and salts that may chemically attack the fracture surface. If chemical damage occurs and if it is not too severe, cleaning techniques can be implemented that will remove the oxidized or corroded surface layer and will restore the fracture surface to a state representative of its original condition.

Mechanical damage of the fracture surface that occurs during the fracture event usually results from loading conditions. If the loading condition is such that the mating fracture surfaces contact each other, the surfaces will be mechanically damaged. It is also result due to improper handling or transporting of the fracture. It is easy to damage a fracture surface while opening primary cracks, sectioning the fracture from the total part, and transporting the fracture. Other common ways of introducing mechanical damage include fitting the two fracture halves together or picking at the fracture with a sharp instrument. Careful handling and transporting of the fracture are necessary to keep damage to a minimum. If mechanical damage occurs on the fracture surface, nothing can be done to remove its obliterating effect on the original fracture morphology (*Dahlberg et al., 1981 [6]*).
The best way to preserve a fracture is to dry it with gentle stream of dry compressed air, then store it in a desiccators, a vaccum storage vessel or a sealed plastic bag containing a desiccant (*Totten et al., 2008 [7]*). However, such isolation of the fracture is often not practical. Therefore, corrosion- preventive surface coating must be used to inhibit oxidation and corrosion of the fracture surface. The surface coating provided should not react with the base metal and environment. Surface coating must be completely and easily removed without damaging the fracture.

3.2 CUTTING OF FRACTURE

It is often necessary to remove the portion containing a fracture from the total part, because the total part is to be repaired, or to reduce the specimen to a convenient size. Many of the examination tools such as the scanning electron microscope and the electron microprobe analyzer have specimen chambers that limit specimen size. Records, either drawings or photographs, should be maintained to show the locations of the cuts made during sectioning.
All cutting should be done such that fracture faces and their adjacent areas are not damaged or altered in any way; this includes keeping the fracture surface dry whenever possible. For large parts, the common method of specimen removal is flame cutting. Cutting must be done at a sufficient distance from the fracture so that the microstructure of the metal underlying the fracture surface is not altered by the heat of the flame and so that none of the molten metal from flame cutting is deposited on the fracture surface. Saw cutting and abrasive cutoff wheel cutting can be used for a wide range of part sizes. Dry cutting is preferable because coolants may corrode the fracture or may wash away foreign matter from the fracture. A coolant may be required; however, if a dry cut cannot be made at a sufficient distance from the fracture to avoid heat damage to the fracture region. In such cases, the fracture surface should be solvent cleaned and dried immediately after cutting. Some of the coating procedures mentioned above may be useful during cutting and sectioning. For example, the fracture can be protected during flame cutting by taping a cloth over it and can be protected during sawing by spraying or coating it with a lacquer or a rust-preventive compound.

3.3 CLEANING OF FRACTURE

Fracture surfaces exposed to various environments generally contain unwanted surface debris, corrosion or oxidation products, and accumulated artifacts that must be removed before fractography can be performed (*Dahlberg et al., 1974 [8]*).The most common techniques for cleaning fracture surfaces are: Dry air blast or soft organic-fiber brush cleaning, Replica stripping, Organic-solvent cleaning, Water base detergent cleaning, Cathodic cleaning and Chemical-etch cleaning.

3.4 VISUAL INSPECTION

Visual examination is performed to gain an overall understanding of the fracture. The entire fracture surface should be visually inspected to identify the location of the fracture-initiating site or sites and to isolate the areas in the region of crack initiation. In addition to locating the failure origin, visual analysis is necessary to detect any macroscopic features relevant to fracture initiation and propagation.

3.5 ELECTRON FRACTOGRAPHY

Fractography is an indispensable tool in failure analysis. Failure analysis basically tries to correlate failure appearance with failure cause. Fractography atlases and failure analysis handbooks, which precisely describe the relation between cause and appearance, can be used for solving failure problems. Scanning electron microscopy is successfully used in tracing local material abnormalities that act as fatigue crack initiators. By revealing specific fractographic characteristics, complemented by information about the material and the loading conditions, scanning electron microscopy provides a strong indication of the probable cause of failure. In most of the cases related to turbine blade investigation, the fracture surfaces of cracked blades consisted of three regions of different fracture morphology: (a) a corrosion influenced rough fracture area near the origin of the crack (b) a high cycle fatigue fracture area often containing characteristics beach marks (c) an overloaded fracture area.

IV. METALLOGRAPHY

The study of the structure of metals and of metal alloys through the examination of specimens with a metallurgical microscope is termed as metallography. Presently, several types of microscope such as transmission electron microscope (TEM), scanning electron microscope (SEM), auger microscope, ultrasonic microscope, acoustic microscope etc.; are available to perform metallography of the metals and alloys (*Das, 1999 [9]; Johari et al., 1968, 1969 [10, 11]; Zipp 1983 [12]*)).

The various analysis techniques used in metallography includes light optical microscopy (LOM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM).Optical microscopes are used for resolutions down to roughly the wavelength of light (about half a micron) and electron microscope are used for detail below this level, down to atomic resolution. LOM examination should always be performed prior to any electron metallographic (EM) technique, as these are more time-consuming to perform and the instruments are much more expensive. Also, the image contrast of microstructures at relatively low magnifications, less than 500X, is far better with the LOM than with the scanning electron microscope (SEM),

while transmission electron microscopes (TEM). If a specimen observed at higher magnification between 2000 to 3000X, it can be examined with a scanning electron microscope (SEM), or a transmission electron microscope (TEM). When a SEM or a TEM equipped with an energy dispersive spectrometer (EDS), the chemical composition of the microstructural features can be determined.

4.1 SCANNING ELECTRON MICROSCOPY

The surface to be examined is scanned with an electron beam; the reflected beam of electrons is collected, and then displayed at the same scanning rate on a cathode ray tube. The image that appears on the screen, which may be photographed, represents the surface features of the specimen. The surface must be electrically conductive; a very thin metallic coating must be applied to non-conductive materials. Scanning electron microscope with resolution upto 5 nm and magnification nearly $2x10^5$ times are used for observing much finer details. Due to its high depth of field, the scanning electron microscopes are extensively used in fracture study called fractography.

4.2 TRANSMISSION ELECTRON MICROSCOPY

In the TEM, electrons are focused on an extremely thin foil of the material; the beam of electrons interacts with imperfections in the material, causing differences in the fraction of electrons that are transmitted. The transmitted beam is projected onto a fluorescent screen or a photographic film so that the image may be viewed. Transmission electron microscopes with resolution limit upto 0.2nm and magnification nearly $9x10^5$ times are used for observing crystal defects such as grain boundary, dislocations, stacking faults, twining etc. The capability of transmission electron microscope in producing selected area diffraction pattern helps in characterizing crystals defects.

4.3 X-RAY DIFFRACTION TECHNIQUE

Characterization of microstructures has also been performed using x-ray diffraction (XRD) techniques for many years. XRD can be used to determine the percentages of various phases present in a specimen if they have different crystal structures. If a particular phase can be chemically extracted from a bulk specimen, it can be identified using XRD based on the crystal structure and lattice dimensions. This work can be complemented by energy dispersive spectrometer (EDS) analysis where the chemical composition is quantified.

V. SAMPLE PREPARATION FOR OPTICAL METALLOGRAPHY AND SCANNING ELECTRON MICROSCOPY (SEM)

The success of any metallographic study is primarily dependent on proper sample preparation. The preparation of a specimen to reveal its microstructure involves cutting the section to be examined, mounting the sample in resins (if sample is too small), grinding the sample on progressively finer emery paper, Polishing and Etching the sample.

5.1 CUTTING

A sample is cut from the examined area. The size of the sample should be compatible with the microscope stage. The sample cut in this research work is 6mmx6mm size. Hand sawing, abrasive cutting with proper cooling, chemical and electro-chemical sectioning are preferred to faster cutting such as flame cutting, laser cutting, electron discharge machining etc.

5.2 MOUNTING

With very small or irregularly shaped specimens it is generally more convenient to mount them in a resin. Bakelite is commonly used. Also, more than one specimen from a single component can be mounted and therefore polished at the same time. Never mount dissimilar metals in the same mount.

Fig. 1: Turbine blade specimens mounted in Bakelite

5.3 GRINDING

The purpose of grinding is to remove the deformed materials and also to reduce the surface roughness caused by cutting operation. Successive grinding with coarse to fine abrasive particles results in a flat surface with fine scratches. Emery papers of grit sizes 60, 120, 220, 320, 400 and 600 are commonly used in six steps. The sample should be moved forward and backward on

the paper until the whole surface is covered with unidirectional scratches. It is then washed with running water to remove debris associated with the grade of paper used. It is then ground on the next finer paper such that the scratches produced are at right angles to those formed by the previous paper. This procedure is repeated through the range of papers available. When the specimen has been ground on the final paper, it is generally worthwhile rotating it through and grinding again with less pressure than before. This technique can decrease the time required for the next stage, which is polishing.

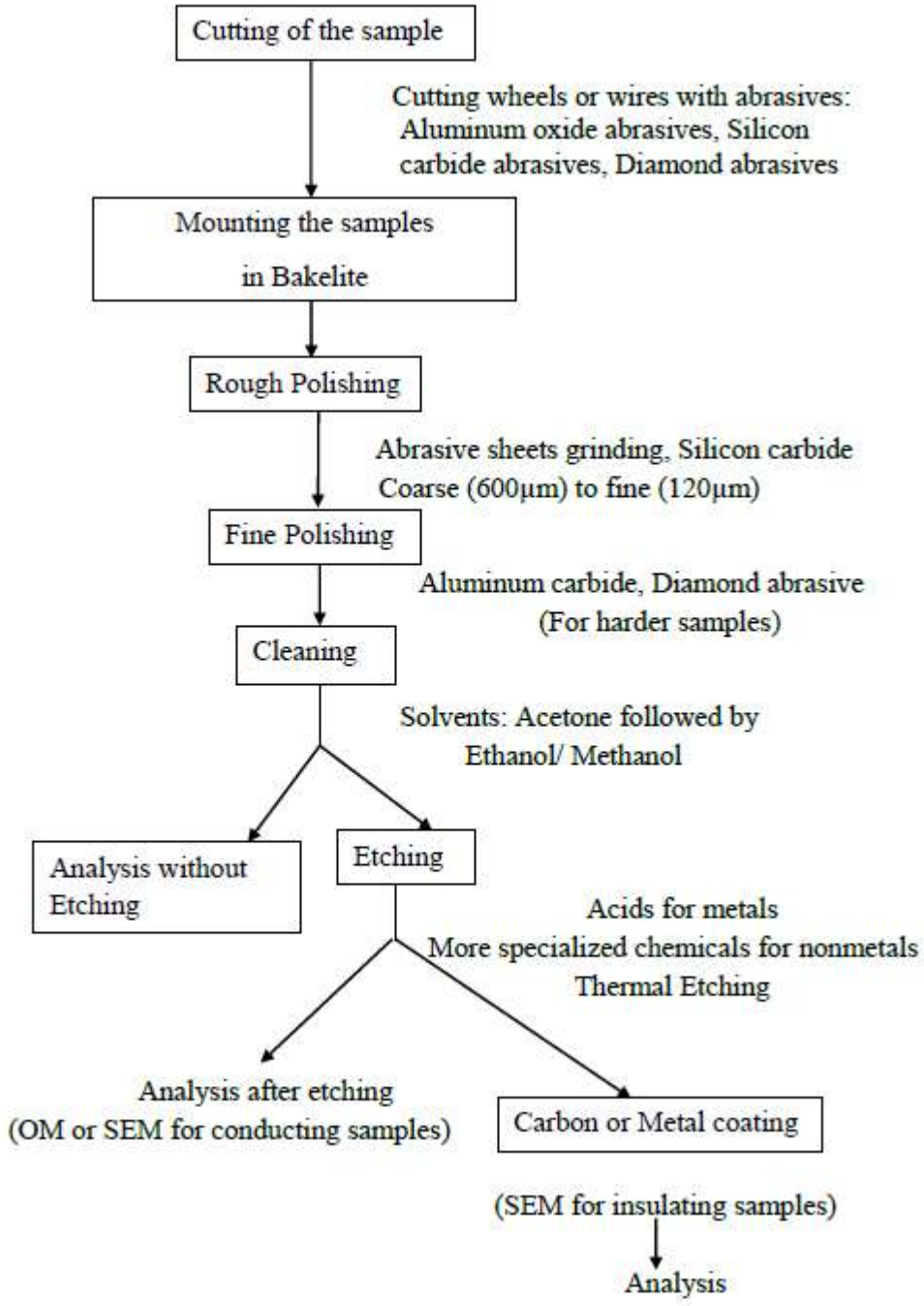

Fig. 2: Basic steps involved in sample preparation for fractographic analysis

5.4 POLISING

Polishing is the most important step in preparing sample for microstructural analysis. Polishing is a complex activity in which factors such as quality and suitability of cloth, abrasive, polishing pressure, polishing speed and duration need to be taken into account. The quality of surface obtained after the final polishing depends on all these factors and the finish of the surface on completion of each previous stages.

After grinding the sample, either manual or electrolytic polishing is carried out to produce a perfectly flat mirror like smooth surface by removing the fine scratches produced during grinding. Manual polishing is done by holding the flat ground surface on a cloth covered rotating wheels smeared with abrasive (Al_2O_3) suspension. 20 µm and 10 µm Al_2O_3particle suspension and 5µm diamond paste is used in three successive polishing steps. Electrolytic polishing is carried out by anodic dissolution in electrolyte cell. The cell consists of a container filled with electrolyte and stainless steel or platinum cathode immersed in it. The

sample as anode is placed in the cell and D.C. supply is connected to the cathode and anode. Selective anodic dissolution of protrusions of grinding scratches results in a mirror like smooth surface.

5.5 ETCHING

Features such as pores, pits, cracks, inclusions and relief formation due to difference in hardness are visible in optical microscope in the polished sample. But other microstructural details such as grain size, segregation, the shape, size, and distribution of the phases, inclusions and grain boundary are revealed on polished surface with a technique called etching. The main etching processes used in metallographic sample preparation are chemical etching, electrolytic etching and heat tinting.

(a) Chemical Etching:

This etching process involves immersing the sample in an etchant or swabbing the surface with an etchant. . The selection of the optimum etchant and immersion time are very important in sample production. Deeper etches are preferred for low magnification examinations, while shallow etches are preferred for higher magnification etches.

(b) Electrolytic Etching

Electrolytic etching and electrolytic polishing are in effect the same process, except that electrolytic etching uses lower voltages and current densities. Most electrolytic etching processes use direct current electrolysis. The process uses the specimen as the anode, with the cathode being a highly insoluble, but conductive material such as platinum, graphite and stainless steels.

(c) Heat tinting

Heat tinting, sometimes called thermal etching is the process of oxidizing a sample in a furnace. This induces oxidation of surface features at different rates, to reveal various features (*Rooth et al. 1997, [13]).*

VI. CONCLUSIONS

In this work the various methodologies, which are employed to investigate the failure in turbine blade have been discussed and illustrated. The following conclusions are drawn:

1. Fractography and metallography methodologies used for investigating blade failures are illustrated in detail.
2. With the help of these methodologies, one may easily identify the root cause of failure of turbine blade; whether it is material defect or maintenance defect or the defect arise due to working environment inside the turbine casing.
3. All the steps involved in preparation of sample for metallographic investigations have been discussed in detail.

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