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A Review of Various Techniques Used for Shaft Failure Analysis

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ABSTRACT - The various methodology used for failure analysis of the shaft used in different application by various authors are reviewed in this paper. This paper presents the comparison of the different methodology used, their application and limitation by various authors. The objective of present work is to study the various methodologies used for the shaft failure analysis and to choose best methodology suitable for the failure analysis of shaft used in gear box which is mounted on the overhead crane to prevent repetitive failure.

Shaft failure leads to heavy loss due to stoppage and repairing cost associate with the breakdown.

Keywords: Shaft failure, Methodology, Overhead crane, Failure Analysis, Stresses.

I. INTRODUCTION

A shaft [1] is a rotating member usually of circular cross-section (solid or hollow), which is used to transmit power and rotational motion in machinery and mechanical equipment in various applications. Most shafts are subjected to fluctuating loads of combined bending and torsion with various degrees of stress concentration. For such shafts the problem is fundamentally fatigue loading. Failures of such components and structures have engaged scientists and engineers extensively in an attempt to find their main causes and thereby offer methods to prevent such failures.

A crane is mechanical equipment for lifting and lowering a load and moving it horizontally with the hoisting mechanism an integral part of the machine. A crane with a single or multiple girder movable bridge, carrying a movable trolley or fixed hoisting mechanism and travelling on an overhead fixed runway structure is known as overhead crane. Material handling is a vital component of any manufacturing and distribution system and the material handling industry is consequently active, dynamic and competitive. Overhead crane is used for material handling purpose and hence it is very useful for any industry.

II . BACKGROUND OF FAILURE ANALYSIS

Failure analysis is [2] the process of collecting and analyzing data to determine the cause of a failure and how to prevent it from recurring. It is an important discipline in many branches of manufacturing industry. Such as the electronics industry where it is a vital tool used in the development of new products and for the improvement of existing products. However, it also applied to other fields such as business management and military strategy. Failure analysis and prevention are important functions to all of the engineering disciplines. The materials engineer often plays a lead role in the analysis of failures, whether a component or product fails in service or if failure occurs in manufacturing or during production processing. In any case, one must determine the cause of failure to prevent future occurrence or to improve the performance of the device, component or structure.

Failure analysis can have three broad objectives.

1. Determining modes
2. Failure Cause
3. Root causes.

Failure mode can be determined on-site or in the laboratory, using methods such as fractography, metallographic and mechanical testing. Failure cause is determined from laboratory studies and knowledge of the component and its loading and its environment. Comparative sampling or duplication of the failure mode in the laboratory may be necessary to determine the cause. Root failure cause is determined using knowledge of the mode, the cause and the particular process or system. Determining the root failure cause require complete information about the equipment's design, operation, maintenance, history and environment. A typical failure analysis might include fractography, metallographic and chemical analysis. Failure analysis of a rear axle of an automobile was discussed in [7].

The failed component is examined and its condition documented. If appropriate, scale or deposits are collected and any fracture surface features are documented. A scanning electron microscope (SEM) is often used to evaluate fracture surfaces for material defects, determine fracture modes and measure fracture features and particles precisely. Metallographic is particularly powerful when combined with typical non-destructive examination (NDE) methods such as ultrasonic testing, eddy current, magnetic particle testing or liquid penetrate testing. Failure of a component indicates it has become completely or partially unusable or has deteriorated to the point that it is undependable or unsafe for normal sustained service. There are some of typical root cause failure mechanisms such as fatigue failures that cause by repeating cycle, corrosion failures, stress corrosion cracking, ductile and brittle fractures, hydrogen embrittlement, liquid metal embrittlement, creep and stress rupture. It is possible for fracture to be a result of multiple failure mechanisms or root causes. A failure analysis can provide the information to identify the appropriate root cause of the failure. The common causes of failure are like misuse or abuse, assembly errors by manufacturer, improper maintenance, design errors, improper material and heat treatment process for the material and manufacturing defect like unforeseen operating condition and inadequate environmental protection or control [10].

Fig.1 .failure of shaft

III. Causes and Analysis of Shaft failure

1. Causes of failure

Austin H. Bonnett, [3] discuss the causes of shaft failures. This paper focus on failures associated with fatigue.

Table No.1 Causes of shaft failure

CAUSE OF SHAFT FAILURES	PERCENT
Corrosion	29%
Fatigue	25%
Brittle Fracture	16%
Overload	11%
High-Temperature Corrosion	7%
Stress Corrosion Fatigue/Hydrogen Embrittlement	6%
Creep	3%
Wear, Abrasion, and Erosion	3%

XU Yanhui[4] says that shaft damaged can be induced by sub synchronous resonance(SSR).

J.feller[5]fatigue loading on wind turbine drive trains due to the fluctuating nature of wind is major cause of premature failure of gearboxes. The shaft fail due to fatigue, which arises due to following reasons [4]

a. Presence of cyclic over-loads
b. Stress concentration. They may be due to production or operation causes e.g. under cuts, machining, traces, knotches etc.
c. Wrong adjustment of bearing, insufficient clearances.

In corrosion failures, the stress is the environment and there action it has on the shaft material. At the core of this problem is an electrochemical reaction that weakens the shaft.

Eccentric Shaft is widely appreciated for its features like corrosion resistant, long service, effective performance and reliability[5].

Corrosion is a process that occurs when oxygen, water, acids and salts mix together. The temperature must be above 0˚C, when the relative humidity is below 40% almost no corrosion from 40-60% (relative humidity) significant corrosion is to be expected [27].

The redox (reduction-oxidation-reaction) is a chemical reaction. Thus happens when one electron is transferred to the other. In such an electron transfer reaction the electron cuts (oxidation) through a material on an electron uptake (reduction).

Many structural alloys corrode merely from exposure to moisture in air [3] but the process can be strongly affected by exposure to certain substances. Corrosion can be concentrated locally to form a pit or crack or it can extend across a wide area more or less uniformly corroding the surface. Because corrosion is a diffusion-controlled process it occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface such as passivation and chromate conversion can increase a material's corrosion resistance. However, some corrosion mechanisms are less visible and less predictable. Many times corrosion will act in conjunction with fatigue loading to cause a shaft failure [11].

According to Osgood all machine and structural designs have problems in fatigue [8]. Failure of an elevator shaft due torsion-bending fatigue was given in [9]. Overload failures are caused by forces that exceed the yield strength or the tensile strength of a material. The appearance of an overload failure depends on whether the shaft material is brittle or ductile [11].

1. Miscellaneous non fracture-type shaft failure

There is a broad category of shaft failures or motor failures that does not result in the shaft breaking. The following is a list of the more common causes (it is acknowledged that fatigue failures that are caught in the early stages would also fit in the non fracture category)[3].

- Bending or deflection causing interference with stationary parts
- Incorrect shaft size causing interference, run out or incorrect fit
- Residual stress causing a change in shaft geometry
- Material problems
- Excessive corrosion and wear.

2. The tools of shaft failure analysis

The ability to properly characterize the microstructure and the surface topology of a failed shaft are critical steps in analyzing failures[3].

1) Visual inspection
2) Optical microscope
3) Scanning Electron Microscope
4) Transmission electron microscope
5) Metallurgical analysis

Fig.2. Failure caused by rotational bending [3]

Fig.3. Shaft fatigue [3]

Fig. 4. Failure due to reverse torsional loading [3]

IV. Fatigue failure

One of the more common causes of shaft failure is due to fatigue. Metal fatigue is caused by repeated cycling of the load [7]. It is a progressive localized damage due to fluctuating stresses and strains on the material. Metal fatigue cracks initiate and propagate in regions where the strain is most sever. The concept of fatigue is very simple when a motion is repeated the object that is doing the work becomes weak. Fatigue occurs when a material is subject to alternating stresses, over a long period of time. Examples of where Fatigue may occur are: springs, turbine blades, airplane wings, bridges and bones.

There are 3 steps that maybe view a failure of a material due to fatigue on a microscopic level:

1. Crack Initiation: The initial crack occurs in this stage. The crack may be caused by surface scratches caused by handling or tooling of the material, threads (as in a screw or bolt), slip bands or dislocations intersecting the surface as a result of previous cyclic loading or work hardening.
2. Crack Propagation: The crack continues to grow during this stage as a result of continuously applied stresses.
3. Failure: Failure occurs when the material that has not been affected by the crack cannot withstand the applied stress. This stage happens very quickly.

Location of the 3 steps in a fatigue fracture under axial stress.

One can determine that a material failed by fatigue by examining the fracture sight. A fatigue fracture will have two distinct regions; One being smooth or burnished as a result of the rubbing of the bottom and top of the crack (steps 1 & 2).
The second is granular, due to the rapid failure of the material.

The most effective method of improving fatigue performance is improvements in design [3].

a. Eliminate or reduce stress raisers by stream lining the part
b. Avoid sharp surface tears resulting from punching, stamping, shearing or other processes
c. Prevent the development of surface discontinuities during processing. Reduce or eliminate tensile residual stresses caused by manufacturing.
d. Improve the details of fabrication and fastening procedures

Metal fatigue is a significant problem because it can occur due to repeated loads below the static yield strength. This can result in an unexpected and catastrophic failure in use because most engineering materials contain discontinuities. Most metal fatigue cracks initiate from discontinuities in highly stressed regions of the component. The failure may be due the discontinuity, design, improper maintenance or other causes. A failure analysis can determine the cause of the failure.

Understanding fatigue [3] strength and endurance limits is important because most shaft failures are related to fatigue associated with cyclic loading. These limits are expressed by an S–N diagram, as shown in Fig. 5.

For steel, these plots become horizontal after a certain number of cycles. In this case, a failure will not occur as long as the stress is below 27 klbf/in. No matter how many cycles are applied. However, at 10 cycles, the shaft will fail if the load is increased to 40 bf/in. The horizontal line in Fig. 8 is known as the fatigue or endurance limit. For the types of steels commonly used for motors, good design practice dictates staying well below the limit. Problems arise when the applied load exceeds its limits or there is damage to the shaft that causes a stress raiser.

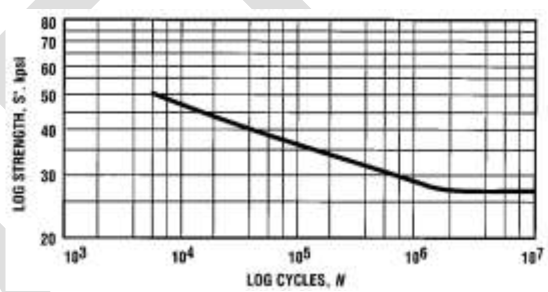

Fig. 5 S-N curve [3]

V. Modes of fracture

1. Monotonic Overload

i. Brittle: Brittle fracture may occur at stresses for below the yield strength. In case of materials subjected to impact and shock loads and usually occur without warning. Brittle fractures are most likely to occur on large-sized components or structures as a result of shock loading.

ii. Ductile: If a material is subjected to load above the yield point and the process of deformation continues, fracture eventually occur. Ductile fractures require a considerable amount of energy to plastically deform the material in necking region. Ductile fractures are very important in metal working operations, such as deep drawing, forging etc.

2. Subcritical Crack Growth

A. Failure under static load Parts under static loading may fail due to:

i. Ductile behaviour: Failure is due to bulk yielding causing permanent deformations that are objectionable. These failures may cause noise, loss of accuracy, excessive vibrations and eventual fracture. In machinery bulk yielding is the criteria for failure. Tiny areas of yielding are in ductile behaviour in static loading.

ii. Brittle behaviour: Failure is due to fracture. This occurs when the materials (or conditions) do not allow much yielding such as ceramics, grey cast iron, or heavily cold-worked parts.

B. Dynamic loading:

Under dynamic loading, materials fail by fatigue. Fatigue failure is a familiar phenomenon fatigue life is measured by subjecting the material to cyclic loading. The loading is usually uniaxial tension, but other cycles such as torsion or bending can be used as well.

Fatigue failures are caused by slow crack growth through the material. The failure process involves four stages
1. Crack initiation
2. Micro-crack growth (with crack length less than the materials grain size) (Stage I)
3. Macro crack growth (crack length between 0.1mm and 10mm) (Stage II)
4. Failure by fast fracture.

Cracks initially propagate along the slip bands at around 45 degrees to the principal stress direction this is known as Stage I fatigue crack growth. When the cracks reach a length comparable to the materials grain size, they change direction and propagate perpendicular to the principal stress. This is known as Stage II fatigue crack growth.

VI. Theories of failure

1. Maximum principal stress theory - Good for brittle materials

According to this theory when maximum principal stress induced in a material under complex load condition exceeds maximum normal strength in a simple tension test the material fails. So the failure condition can be expressed as

$$\sigma_1 \geq \sigma_{ult}$$

2. Maximum shear stress theory - Good for ductile materials

According to this theory when maximum shear strength in actual case exceeds maximum allowable shear stress in simple tension test the material case. Maximum shear stress in actual case in represented as

$$\tau_{max,act} = \frac{\sigma_1 - \sigma_3}{2}$$

Maximum shear stress in simple tension case occurs at angle 45 with load, so maximum shear strength in a simple tension case can be represented as

$$\tau_{45} = \tau_{max,act} = \frac{\sigma_y}{2}$$

Comparing these 2 quantities one can write the failure condition as

$$\frac{1}{2}(\sigma_1 - \sigma_3) \geq \frac{1}{2}\sigma_y$$

3. Maximum normal strain theory - Not recommended

This theory states that when maximum normal strain in actual case is more than maximum normal strain occurred in simple tension test case the material fails. Maximum normal strain in actual case is given by

$$\text{strain}_{\text{max,act}} = \frac{\sigma_1}{E} - v\frac{\sigma_2}{E} - v\frac{\sigma_3}{E}$$

Maximum strain in simple tension test case is given by

$$\text{strain}_{\max} = \frac{\sigma_y}{E}$$

So condition of failure according to this theory is

$$\frac{\sigma_1}{E} - v\frac{\sigma_2}{E} - v\frac{\sigma_3}{E} \geq \frac{\sigma_y}{E}$$

Where *E* is Youngs modulus of the material

4. Total strain energy theory - Good for ductile material

According to this theory when total strain energy in actual case exceeds total strain energy in simple tension test at the time of failure the material fails. Total strain energy in actual case is given by

$$T.S.E_{act} = \frac{1}{2E}[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2v(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)]$$

Total strain energy in simple tension test at time of failure is given by

$$T.S.E_{simp} = \frac{\sigma_y^2}{2E}$$

So failure condition can be simplified as

$$\frac{1}{2E}[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2v(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)]$$

5. Shear strain energy theory - Highly recommended

According to this theory when shear strain energy in actual case exceeds shear strain energy in simple tension test at the time of failure the material fails. Shear strain energy in actual case is given by

$$S.S.E_{act} = \frac{1}{12G}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]$$

Shear strain energy in simple tension test at the time of failure is given by

$$S.S.E_{simp} = \frac{\sigma_y^2}{6G}$$

So the failure condition can be deduced as

$$\frac{1}{12G}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2] \geq \frac{\sigma_y^2}{6G}$$

Where *G* is shear modulus of the material

VII. Tools used for shaft failure analysis

Non destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. The terms Non destructive examination (NDE), Non destructive inspection (NDI) and Non destructive evaluation (NDE) are also commonly used to describe this technology.

a. Magnetic Particle inspection

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Magnetic Particle Inspection (MPI)[13] is a non-destructive testing (NDT) process for detecting surface and slightly subsurface discontinuities in ferromagnetic materials such as iron, nickel, cobalt, and some of their alloys and must be performed to worldwide standards such as EN473 and ISO9712 by qualified personnel. The process puts a magnetic field into the part. The piece can be magnetized by direct or indirect magnetization. Direct magnetization occurs when the electric current is passed through the test object and a magnetic field is formed in the material. Indirect magnetization occurs when no electric current is passed through the test object, but a magnetic field is applied from an outside source. The magnetic lines of force are perpendicular to the direction of the electric current which may be either alternating current (AC) or some form of direct current (DC) (rectified AC).

A close-up of the surface of a (different) pipeline showing indications of stress corrosion cracking (two clusters of small black lines) revealed by magnetic particle inspection. Cracks which would normally have been invisible are detectable due to the magnetic particles clustering at the crack openings. The scale at the bottom is numbered in centimetres [13].

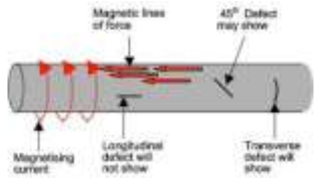

Fig.6 Magnetic Particle Inspection

The presence of a surface or subsurface discontinuity in the material allows the magnetic flux to leak, since air cannot support as much magnetic field per unit volume as metals [14]. Ferrous iron particles are then applied to the part. The particles may be dry or in a wet suspension. If an area of flux leakage is present, the particles will be attracted to this area. The particles will build up at the area of leakage and form what is known as an indication.

b. Residual Stress Failures

These stresses are independent of external loading on the shaft. Many manufacturing or repair operations can affect the amount of residual stress, including [3].

- drawing
- bending
- straightening
- machining
- grinding
- surface rolling
- shot blasting or peening
- polishing.

All of these operations can produce residual stresses by plastic deformation. In addition to the above mechanical processes, thermal processes that introduce residual stress include:

- hot rolling
- welding
- torch cutting
- heat treating

All residual stress may not be detrimental, if the stress is parallel to the load stress and in an opposite direction, it may be beneficial. Proper heat treatment can reduce these stresses if they are of excessive levels.

a. Radiography

Radiography is [13] a non-destructive testing method which utilizes radiation to penetrate the material under test. The radiation sources have extremely short wavelengths, of about 1/10000th that of visible light. Two types of radiation source are commonly used for industrial radiography, x-rays and gamma rays from radioactive isotopes.

Fig.7 Radiography testing machine

Image capture [14] is another important aspect of radiography. The most common method in use is to capture images on film. Radiography is carried out based on the geometrical shape of the material and the information required. The configuration of the sample with respect to the placement of the film radiation source has considerable influence on the information that can be obtained.

Radiographers use a Radiographic Image Quality Indicator (IQI) or penetrameter as a quality assurance tool.

b. Liquid Penetrant Testing

Liquid Penetrant Testing (PT) is based on capillary action and is a very effective test method that exposes surface-opening discontinuities for visual inspection. Either fluorescent or visible dyes are used.

Fig.8 Liquid Penetrant Testing

The surface is first prepared to remove anything that could obscure surface openings or otherwise interfere with the examination and then it is dried. The penetrant is applied by a suitable means and after the specified penetration time has elapsed any remaining penetrant on the material surface is removed. The developer is applied immediately. Final interpretation needs to be made within 7 to 60min after the dwell time of developer.

c. Electromagnetic Inspection

Electromagnetic Testing (ET), [13]as a form of non-destructive testing is the process of inducing electric currents or magnetic fields or both inside a test object and observing the electromagnetic response. If the test is set up properly a defect inside the test object creates a measurable response.

Fig.9 Electromagnetic Inspection Testing

The term "Electromagnetic Testing" is often intended to mean simply Eddy-Current Testing (ECT). However with an expanding number of electromagnetic and magnetic test methods, "Electromagnetic Testing" is more often used to mean the whole class of electromagnetic test methods, of which Eddy-Current Testing is just one [14].

Ultrasonic InspectionIn ultrasonic testing (UT) [13] very short ultrasonic pulse-waves with centre frequencies ranging from 0.1-15 MHz and occasionally up to 50 MHz are transmitted into materials to detect internal flaws or to characterize materials. A common example is ultrasonic thickness measurement which tests the thickness of the test object for example to monitor pipe work corrosion.

Fig.10 Ultrasonic Inspection

Ultrasonic testing [14] is often performed on steel and other metals and alloys, though it can also be used on concrete, wood and composites albeit with less resolution. It is a form of non-destructive testing used in many industries including aerospace, automotive and other transportation sect.

B. Role of metallographic Examination

1. The Optical Microscope

The optical microscope use for phase identification. The optical microscope, often referred to as the "light microscope", is a type of microscope which uses visible light and a system of lenses to magnify images of small samples (10X, 40X. . . 2000X) magnifies the beam.

Fig.11 Optical Microscope

The optical microscope is most commonly used for the analysis Specimen to be observed, the sample is to ground first by using different grain sizes sand paper. Then polished like mirror image and then etched with a solution for a certain length. Careful technique is critical in sample preparation is required, otherwise optical microscope is useless. Optical microscopy has several trans-illuminating technique of operation:

1. Bright field illumination, sample contrast comes from absorbance of light in the sample.

2. Transmission mode is commonly used for transparent specimens mounted on glass slides. This mode is commonly used for biological specimens.

3. Dark field illumination, sample contrast comes from light scattered by the sample. This method is used for surface contaminant identification.

4. Cross-polarized light illumination, sample contrast

Cross-polarized light illumination, sample contrast comes from rotation of polarized light through the sample

2) Scanning Electron Microscopy (SEM)

The SEM has important role in failure analysis in all the laboratories. The SEM is used for image as well as probe. It uses the high energy electron focused beam to generate signal at solid surface.

SEM equipped with Electron Source (Gun), Electron Lenses, Sample Stage, display unit, Detector. SEM Detectors allow information to be gathered from conductor potential to elemental analysis of materials.

Fig.12 Scanning Electron Microscopy

Various probe methods have evolved associated with the SEM. The SEM is routinely used to generate high-resolution images of objects shapes (SEI) and to show chemical compositions variations. The SEM is a surface imaging tool and cannot image effectively through oxides compared to an optical microscope. SEM is a non destructive as it does not result in loss of sample & can be performed repeatedly.

Osman asi [7] SEM examination revealed some inclusion in the surface close to the crack initiation

3) Heat-affected zone (HAZ*)*

The portion of a metal work-piece that has been so altered by heat is termed the ―heat-affected zone or HAZ. All thermal cutting & welding processes create an HAZ in the metal. The changes induced by heat can include:

1. Altering the microstructure of particular steels, leading to an increase in the hardness of the cut edge relative to the un-cut metal.

2. Altering the microstructure of particular steels, leading to a decrease in the strength.

3. The formation of nitrides on the cut edge, which can affect the weld ability of the cut face.

4. Darkening or discoloration of the surface of the metal next to the cut face (‘heat-tint’).

Osman asi [7] discussed typical micro-fracture appearance fracture surface of the failed axle shaft exhibits heat-affected region (HAZ)leads to crack initiation

Chen lie[22] discuss Laser cladding is especially fit for repairing the wearing high-accuracy components due to the potty heat affected zone.

4) Energy Dispersive X-Ray Spectroscopy (EDX)

Energy Dispersive X-ray analysis (EDX) is also referred as EDS or EDX analysis. EDX is an analytical technique used for the elemental analysis or chemical characterization of a specimen. The EDX system works as an integrated feature of the SEM and cannot operate on its own. During EDX Analysis, the object is bombarded by electron beam inside the SEM. Those electrons collide with the specimen's own electrons, knocking some of them off in the process. When the electron is displaced, it gives up some of its energy by emitting an X-ray. Every element releases X-rays with unique amounts of energy during the transfer process. Thus, by measuring the amounts of energy present in the X-rays being released by a specimen during electron beam bombardment, the atom identity can be known. A detector used to convert X-ray energy into voltage signals; this signal is sent to a pulse processor, which measures the signals and passes them onto an analyzer for data display and analysis. The detector used is Si(Li) detector. Also new system equipped with silicon drift detectors (SDD) with Peltier cooling systems are gaining more popularity.

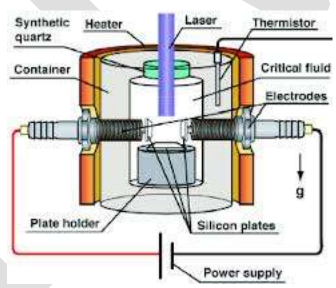

Fig.13 Energy Dispersive X-Ray Spectroscopy

Osman Asi [7] carried out EDX analysis indicated the main elements of these inclusions are O, Ca, Si, Al and Mg which are not contained in the original material (except Si). Such components are often seen in improper welded location of steels. These also act as crack initiation

C. MECHANICAL TESTING

a. Hardness testing

Different Methods of Hardness Testing: There are four typical methods for testing the hardness of metals. These are the sclerometer method introduced by Turner in 1896, the scleroscope method recently invented by Shore, the indentation test adopted by Brinell about 1900 and the drill test introduced by Keep a few years earlier. The principles underlying each of the four methods are briefly described in the following [15] [19].

Fig.14 Hardness Testing Machine

1. Turner's Sclerometer: In this form of test a weighted diamond point is drawn, once forward and once backward, over the smooth surface of the material to be tested. The hardness number is the weight in grams required to produce a standard scratch. The scratch selected is one which is just visible to the naked eye as a dark line on a bright reflecting surface. It is also the scratch which can just be felt with the edge of a quill when the latter is drawn over the smooth surface at right angles to a series of such scratches produced by regularly increasing weights.

2. Shore's Scleroscope: In this instrument, a small cylinder of steel, with a hardened point, is allowed to fall upon the smooth surface of the metal to be tested and the height of the rebound of the hammer is taken as the measure of hardness. The hammer weighs about 40 grains, the height of the rebound of hardened steel is in the neighbourhood of 100 on the scale, or about 6-1/4 inches, while the total fall is about 10 inches or 254 millimetres.

3. Brinell's Test: In this method, a hardened steel ball is pressed into the smooth surface of the metal so as to make an indentation of a size such as can be conveniently measured under the microscope. The spherical area of the indentation being calculated and the pressure being known, the stress per unit of area when the ball comes to rest is calculated and the hardness number obtained. Within certain limits, the value obtained is independent of the size of the ball and of the amount of pressure.

Fig.15 brinell's test

4. Keep's Test: In this form of apparatus a standard steel drill is caused to make a definite number of revolutions while it is pressed with standard force against the specimen to be tested. The hardness is automatically recorded on a diagram on which a dead soft material gives a horizontal line, while a material as hard as the drill itself gives a vertical line, intermediate hardness being represented by the corresponding angle between 0 and 90 degrees.

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behaviour of solid materials under force is complex. Therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness.[26]

b. Fatigue test

A method for determining the behaviour of materials [18] under fluctuating loads. A specified mean load (which may be zero) and an alternating load are applied to a specimen and the number of cycles required to produce failure (fatigue life) is recorded. Generally, the test is repeated with identical specimens and various fluctuating loads. Loads may be applied axially, in torsion or in flexure. Depending on amplitude of the mean and cyclic load, net stress in the specimen may be in one direction through the loading cycle or may reverse direction. Data from fatigue testing often are presented in an S-N diagram which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be stress amplitude, maximum stress or minimum stress. Each curve in the diagram represents a constant mean stress. Most fatigue tests are conducted in flexure, rotating beam, or vibratory type machines. Fatigue testing is generally discussed in [18]"Manual on Fatigue Testing," ASTM STP 91A

Fig.16 Fatigue Testing

c. Tensile Testing

Tensile testing [16]-[17] also known as tension testing, is fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined.

Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required. The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines. The machine must have the proper capabilities for the test specimen being tested. There are three main parameters: force capacity, speed and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.

d. Impact Testing

Two standard tests, the Charpy and Izod, measure the impact energy (the energy required to fracture a test piece under an impact load) also called the notch toughness.

The Charpy test is the test to determine the resistance of a material against shocks.

The test temperature is very important because the resistance does decrease with decreasing temperature. Impact testing fits into two main categories: (a) low velocity impact, and (b) high velocity impact [20]. These two main categories lead to three main types of impact testing. Charpy impact testing and drop weight impact testing fall into the category of low velocity impact testing (here it should be noted that an impact test machine can be used for high velocity impact also[21]. Ballistics impact testing falls into the category of high velocity impact testing. Technology has increased to the point that there are now sophisticated measuring devices for instrumented impact testing.

Fig.17. Impact testing[3]

VIII. Conclusion

The various failure of shaft is discussed in this paper. Some of the failure of shaft is basically due to negligence in repairing and maintenance, special care is to be taken for stress relieving in welding repairing works. So in order to overcome this problem, failure analysis of shaft in gear box for overhead crane is to be done by following steps.

1. Modeling of shaft with the existing dimension.
2. Finding out the various load and stresses on the shaft.
3. Failure analysis of Existing shaft to find out reasons of failure.
4. Based on analysis composition of the shaft can be change.
5. Redesign of the shaft.

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