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Overview of a Gas Turbine Blades Power Plant

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ABSTRACT: Power plants that employ turbine blades to generate electricity usually need them to have certain qualities, like high strength, fatigue and corrosion resistance, and temperature tolerance. Super alloys and ceramic composites are common materials used in their construction. Defects or imperfections that might impair the performance and lifetime of turbine blades are a typical issue in their production. Casting flaws, material inclusions, and inadequate cooling during manufacturing are a few examples of these faults. Power plants use strict inspection procedures and quality control measures to reduce these problems and guarantee the dependability of their turbine blades. Improvements in material composition and design are usually required when changing the materials used in turbine blades to boost their effectiveness and performance. Depending on the particular use and intended result, turbine blades can undergo a variety of alterations. Advanced alloy material modifications, coatings, ceramic matrix composites (CMCs), airfoil design optimization, cooling technologies, and tip modifications are a few examples of typical modifications. It's important to note that the specific modifications applied to turbine blades can vary widely depending on the type of turbine (gas, steam, wind, etc.), the operating conditions, and the goals of the modification.

Keywords: Turbine blades, material modifications, electrical power plants

1. INTRODUCTION

Turbines play a crucial role in electrical power production plants. They are used to convert various forms of energy, such as thermal energy from burning fossil fuels or kinetic energy from water or wind, into mechanical energy. This mechanical energy is then used to drive the generators that produce electricity. Turbines are essential components in power plants as they provide the means to harness and convert energy efficiently and reliably. The innovation of material for gas turbine is always required because, higher the capability of the material to withstand elevated temperature, the more will be the efficiency of the engine. In this new era of technology, demand for increasing the parameter of the industrial gas turbine is growing very fast, hence the efficiency must increase. This leads the manufacturers all over the world to develop new technology, new material, and a new method of manufacturing to increase the efficiency of the industrial gas turbine [1]. Among these, the material plays a vital role, hence it should be as such they can withstand the extreme conditions and give maximum efficiency. It is observed that 42% of failure in the gas turbine is due to the failure of turbine blades, therefore, it is an important component to be taken care of. Turbine blades are the critical components in a power plant, failure in the blade causes failure of power plant thus resulting in economic loss for the society. Therefore, it is essential to properly analyse the causes of failure to increase the reliability of the turbine systems [2].

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1.1 DESCRIPTION OF THE PARTS AND CYCLIC FOR GAS TURBINE WORKING

Turbine blades used in power plants for electrical production typically require properties such as high strength, resistance to corrosion and fatigue, and the ability to withstand high temperatures. They are usually made from materials like super alloys or ceramic composites[3].

In a gas turbine, there are several key components related to the flow of gases as shown Fig. 1 and 2:

1. Inlet/Intake: This is where outside air enters the turbine system. It typically includes an air filter and ducting to direct the air towards the compressor.
2. Compressor: The compressor consists of multiple stages of rotating blades that compress the incoming air, increasing its pressure and temperature. This is achieved by converting the kinetic energy of the rotating blades into potential energy of the compressed air.
3. Combustor/Combustion Chamber: After leaving the compressor, the high-pressure, high-temperature air enters the combustion chamber. Here, fuel is injected and mixed with the air, resulting in combustion. The combusted gases generate a high-temperature, high-pressure flow.
4. Turbine: The hot and high-pressure gases from the combustion chamber pass through the turbine section. The turbine is composed of rows of stationary and rotating blades. As the gases flow over the blades, they transfer their energy, causing the turbine rotor to rotate.
5. Exhaust: The exhaust section is where the remaining energy in the gases is converted into useful work or expelled as waste heat. The exhaust gases exit the turbine, and depending on the application, can either be used to power additional equipment (such as in combined cycle power plants) or released into the atmosphere.

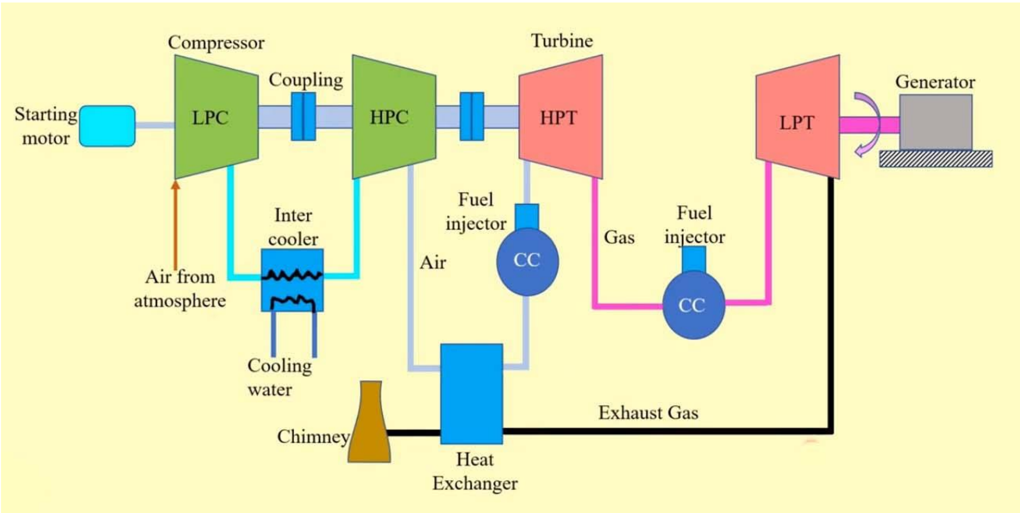


FIGURE 1. - Gas Turbine Diagram

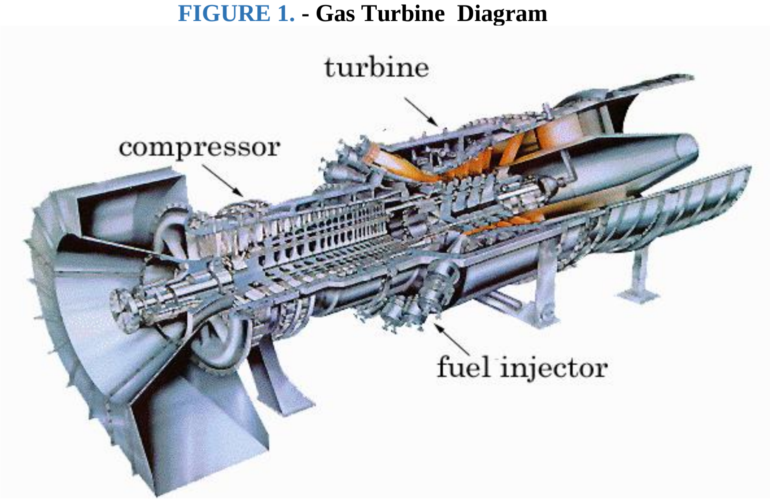


FIGURE 2. - Gas Turbine Part

In a gas turbine, the working process is typically cyclic, consisting of four main stages: intake, compression, combustion, and exhaust. Here's a brief overview[4], as shownFig.3:

1. Intake: Air is drawn into the turbine through an intake system.
2. Compression: The air is compressed by a compressor, typically consisting of multiple stages. Each stage compresses the air, raising its pressure and temperature.
3. Combustion: Fuel is injected into the compressed air, and the mixture is ignited in the combustion chamber. The resulting high-pressure, high-temperature gases expand rapidly, generating power.
4. Exhaust: The exhaust gases, still at high pressure, pass through a turbine, causing it to rotate. The turbine's rotation drives the compressor and any connected machinery, such as an electrical generator or an aircraft propeller. The exhaust gases then exit the turbine and are released into the environment.

This cyclic process repeats continuously to generate continuous power in gas turbines.

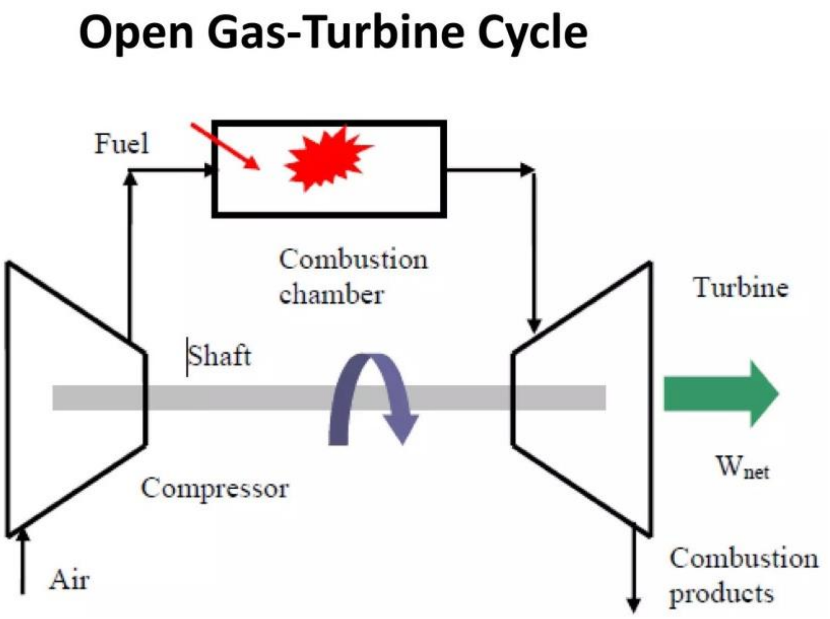


FIGURE 3. - Cyclic process in gas turbine

1.2 THE WORKING CONDITIONS OF GAS TURBINE BLADES

The working conditions of gas turbine blades involve high temperatures, rotational speeds, and exposure to corrosive gases. They operate in extreme environments where temperatures can reach several hundred degrees Celsius. The blades are designed to withstand these conditions while maintaining structural integrity and efficient aerodynamic performance. Cooling mechanisms such as film cooling and internal cooling channels are employed to manage the heat. The materials used for gas turbine blades are typically high-strength alloys, such as nickel-based super alloys, that can withstand the mechanical and thermal stresses. Regular inspections and maintenance are performed to ensure the blades remain in good working condition and to detect any signs of wear or damage , shows Fig. 4[5].

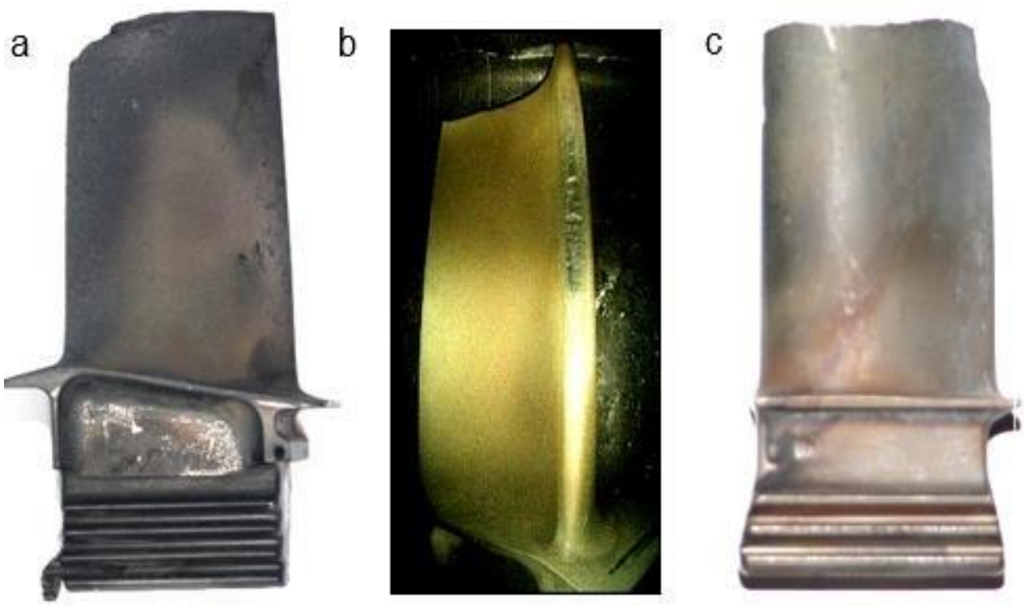


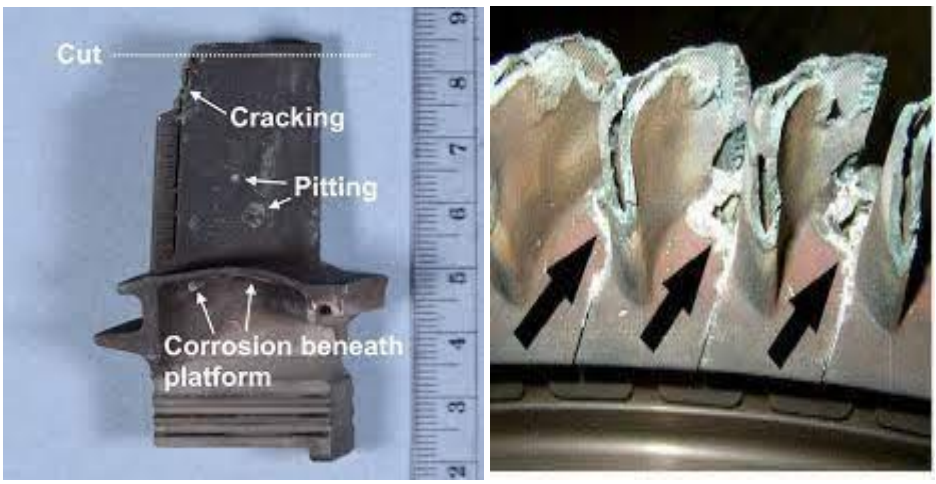
FIGURE 4. - Instances of thermal damages to gas turbine blades:(a); the region of material overheating at the end of the leading edge, (b);overheating region and a fracture on the leading edge, (c); the blade broken off due to material overheating

1.3 PROBLEMS AND SOLVES FOR GAS TURBINE BLADES

One common problem in the production of turbine blades is the formation of defects or flaws, which can compromise their performance and longevity. These defects can include casting defects, material inclusions, or improper cooling during manufacturing. Quality control measures and rigorous inspection processes are employed to minimize these issues and ensure the reliability of turbine blades in power plants[6, 7].

Turbine blade problems in electrical power plants can vary, but here are a few common issues and their possible solutions:

1.Erosion and corrosion: Turbine blades can experience erosion and corrosion due to the harsh operating conditions and exposure to steam and hot gases. Solutions include using erosion-resistant materials, coatings, and regular inspections for timely maintenance and replacement as shown Fig 5 and 6.



Hot corrosion — Mechanism of corrosion

FIGURE 5. - Description the hot corrosion and mechanism of it

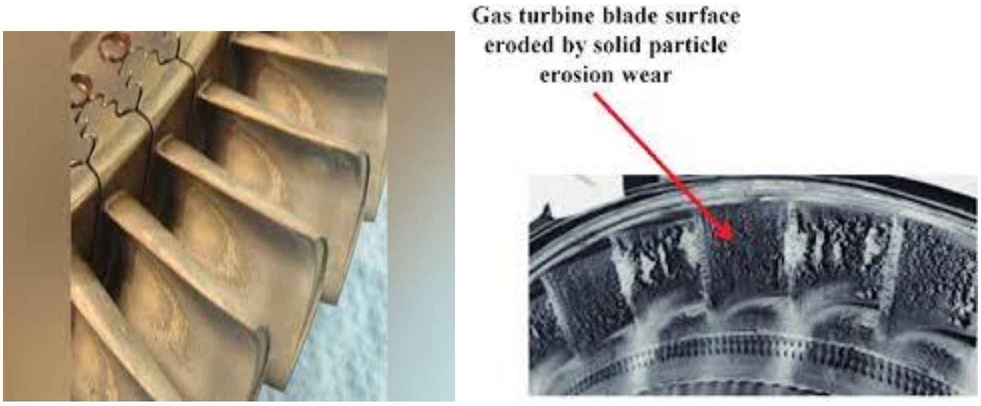


FIGURE 6. - **Sulfidation of gas turbine blades**

2. Fatigue and cracking: Repeated thermal cycles and high rotational speeds can lead to fatigue and cracking in turbine blades. Advanced materials with high fatigue resistance, improved cooling techniques, and regular inspections using non-destructive testing methods can help identify and address cracks before they become critical, as shown Fig.7 .

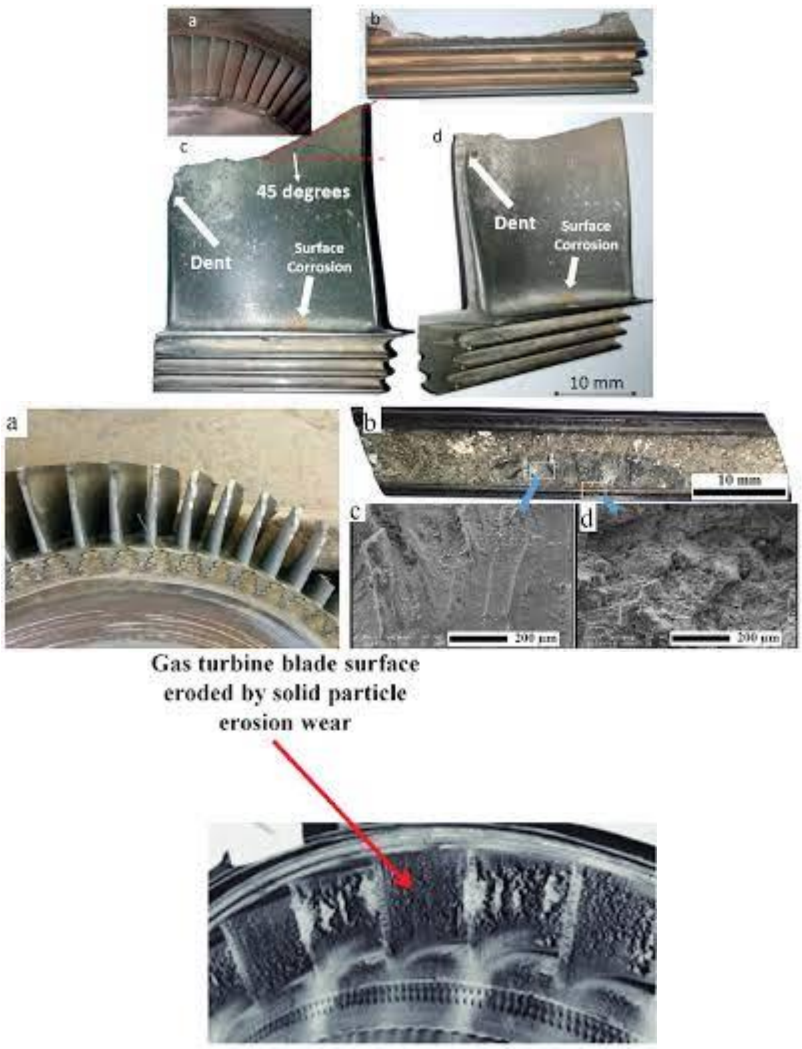


FIGURE 7. - **Fatigue Failure in gas turbine blades**

3. Fouling and deposition: Fouling occurs when foreign substances such as dust, dirt, or salts accumulate on the turbine blades, reducing their efficiency. Proper filtration systems, water treatment, and regular cleaning routines can minimize fouling and deposition, as shown Fig .8.

FIGURE 8. - Heavy hydrated salts fouling in a typical axial compressor Surface roughness

4. Vibration and blade resonance: Excessive vibration and resonance can lead to blade failures. Accurate design and engineering, including vibration analysis and dynamic balancing, can help mitigate these issues. Regular monitoring and maintenance programs can also detect any abnormal vibrations early on, see Fig 9.

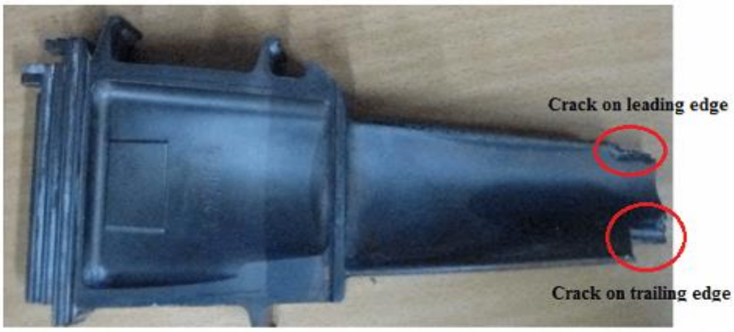


FIGURE 9. - Failed first stage high pressure gas turbine blade collected from site

5. Loss of aerodynamic efficiency: Over time, turbine blades may experience degradation in their aerodynamic performance. Regular cleaning, maintenance, and optimization of blade profiles can help restore and enhance aerodynamic efficiency.

It's important to note that turbine blade problems require expertise from specialized engineers and technicians. Power plant operators typically have dedicated maintenance and inspection programs to address these issues and ensure safe and efficient operation.

The modification of turbine blade materials to increase their performance and efficiency typically involves advancements in material composition and design. Some approaches include [7,8]:

- Advanced alloys: Developing high-temperature alloys with improved mechanical properties, such as enhanced creep resistance and thermal stability, allows turbine blades to withstand harsh operating conditions.
- Coatings: Applying specialized coatings, such as thermal barrier coatings (TBCs) or erosion-resistant coatings, can protect turbine blades from corrosion, oxidation, and wear, increasing their lifespan and performance.
- Ceramic matrix composites (CMCs): Utilizing lightweight and high-temperature resistant CMCs can enhance turbine blade performance by reducing weight, improving thermal efficiency, and withstanding higher temperatures.
- Airfoil design optimization: Refining the aerodynamic design of turbine blades through advanced modeling and simulation techniques helps improve airflow efficiency and reduces energy losses.
- Cooling technologies: Implementing improved internal cooling techniques, such as film cooling or internal cooling channels, helps dissipate heat more effectively, preventing overheating and extending blade life.

These changes are intended to improve overall power generating performance, save maintenance costs, and boost turbine efficiency. The term "modification" refers to alterations or enhancements made to the surface coatings, material composition, or design of the gas turbine blades. These changes may be made to improve durability, lower emissions, boost efficiency, improve performance, or solve certain operating issues. Depending on the intended result and the particular needs of the gas turbine application, different adjustments may be made. Improvements in aerodynamics, thermal barrier coatings, material developments, and cooling methods are examples of common alterations [9].

2. TURBINE BLADES MATERIALS IN GAS TURBINES

Superalloys, which are high-strength, heat-resistant alloys able to withstand the harsh conditions within a gas turbine, are commonly utilised as the materials for turbine blades in gas turbines. These alloys, which are frequently based on nickel or cobalt, are made to withstand high temperatures and severe mechanical strains without losing their mechanical characteristics. Turbine blades are additionally coated with advanced materials to increase their longevity and prevent oxidation and corrosion. Usually, high-performance materials that can tolerate high temperatures and stresses are used to make gas turbine blades. Gas turbine blades are frequently made of the following materials[10,11,12]:

- Superalloys based on nickel: These alloys are ideal for turbine blades because of their exceptional creep resistance, corrosion resistance, and high temperature strength.
- Superalloys with a single crystal microstructure are engineered to have exceptional mechanical characteristics and resilience against fatigue and creep.
- Superalloys that have undergone directionally solidification possess a columnar grain structure, providing a blend of strength, resistance to creep, and thermal stability.
- Ceramic fibers incorporated in a ceramic matrix make up ceramic matrix composites (CMCs). They provide low density, resilience to thermal shock, and stability at high temperatures.
- Thermal barrier coatings (TBCs) are a protective measure against high-temperature oxidation and thermal stresses that are applied to the turbine blade surface. Usually, ceramic materials like yttria-stabilized zirconia are used to make them..

To guarantee the effective and dependable operation of gas turbines, these materials are carefully chosen depending on their qualities. It's crucial to remember, nevertheless, that the specifications and design of a certain gas turbine may change the use of certain materials.

Gas turbine engines employ selective gas turbine blades, sometimes referred to as directionally solidified (DS) or single-crystal (SX) blades, to increase power and longevity. These blades feature a special microstructure that improves their mechanical qualities and are composed of cutting-edge materials such super alloys[13].

The blades can have a homogeneous crystal orientation along the main stress axis, either as a single crystal or as aligned columnar grains, thanks to the selective solidification process. By doing this, the grain boundaries are removed, which could weaken the material and increase its susceptibility to creep and fatigue from mechanical loads and high temperatures.

Selective gas turbine blades have a single crystal or aligned columnar grain structure, which gives them more strength, enhanced creep resistance, and better resistance to thermal fatigue. Because they can run at greater temperatures, engines can produce more power and work more efficiently. These blades also require less cooling because of their enhanced material qualities, which promote heat dissipation.

Selective gas turbine blades are an essential part of the power generating and aerospace sectors because they enhance the overall performance, dependability, and lifetime of gas turbine engines[14].

2.1 GAS TURBINE BLADES TESTS AND EXAMINATIONS

Gas turbine blades are put through a battery of tests and inspections to guarantee their functionality, dependability, and security. Typically, these tests consist of [15]:

1. Non-destructive testing (NDT): NDT techniques, which avoid causing damage to the blades, are used to find surface cracks, flaws, and irregularities. These techniques include visual inspection, dye penetrant testing, magnetic particle testing, and ultrasonic testing.

2. Destructive Testing: To evaluate a blade's strength and material qualities, it may be subjected to destructive testing. To ascertain the blade's resistance to operational stresses, testing in tension, compression, or fatigue may be necessary.

3. Metallurgical Analysis: This method entails looking at the blade material's microstructure to find any anomalies or flaws that might impair its performance

4. Thermal Performance Testing: In order to assess a blade's ability to withstand heat stress and make sure it keeps its shape and integrity while operating, it is placed in high-temperature environments.

5. Vibration and Modal Analysis: In order to understand the dynamic behavior of the blades, vibration and modal analysis are carried out. This aids in locating potential resonance frequencies and potential failure-causing structural flaws.

6. Blade Balancing Tests: These tests make sure the blades are correctly balanced to reduce vibration, increase performance, and stop premature wear.

7. Fatigue Life Assessment: To ascertain a blade's durability and approximate its operational lifespan, fatigue life assessments entail repeatedly loading and unloading it.

2.2 GASES EFFECT

Operators of gas turbines should take into account the particular composition of the gas and any possible impact it may have on the materials and functionality of the blades. Gas turbine blade damage can be lessened by regular maintenance, inspections, and the proper choice of materials.

Depending on the exact fuel composition and combustion properties, different fuels can have different effects on gas turbine blades. But generally speaking [16]:

- High fuel oil is a term used to describe heavy or residual fuel oils that have a high viscosity and energy content. Increased deposits and fouling on gas turbine blades caused by high fuel oil combustion may eventually lower the efficiency and performance of the turbines. To lessen these effects, regular cleaning and maintenance are required.
- Low fuel oil: distillate fuels that are lighter and have less viscosity and sulfur are referred to as low fuel oil. Low fuel oil tends to produce less deposits and fouling on gas turbine blades than high fuel oil, which improves blade performance and lowers maintenance needs.
- In comparison to liquid fuels such as fuel oil, natural gas burns cleaner. Lower pollution and particulate matter levels are produced during its combustion. Natural gas is renowned for having a comparatively minimal effect on fouling and gas turbine blade degradation. Longer stretches of time between maintenance tasks and increased blade efficiency result from this.

Gases: There are a variety of gases that can be used as fuel in gas turbines, so it's unclear to which particular gases you are referring. Depending on how they burn and how pure they are, various gases can affect gas turbine blades in different ways. While some gases, like methane, may not have much of an effect on the deterioration of blades, others, like hydrogen, may be more reactive and cause more severe corrosion of the blades.

Products for Combustion: Gases like carbon dioxide (CO_2), water vapor (H_2O), and nitrogen oxides (NO_x) are produced during combustion. These combustion byproducts may cause deposits on the blades, which may lower their effectiveness and possibly cause erosion or fouling. Composition of Inlet Air: Another important factor is the makeup of the air that enters the turbine. The inlet air contains pollutants, dust, and other particulates that can erode and foul the blades. Elevated relative humidity can cause liquid droplets to form, which can erode or corrode surfaces.

Cooling Gases: In order to keep cooling gases at a consistent temperature, turbine blades frequently contain internal cooling channels. The temperature and pressure of these cooling gases can have an impact on the thermal stress distribution and cooling effectiveness of the blade.

When using various fuels or gases, gas turbine blade longevity and optimal performance are always dependent on proper maintenance, which includes routine cleaning, inspections, and monitoring [20, 21].

2.3 COMPARING THE EFFECTS ON TURBINE BLADES BETWEEN GAS TURBINE AND STEAM TURBINE

The effects on turbine blades differ between gas turbines and steam turbines due to the different operating conditions and working fluids [17,18,19].

Gas Turbines:

- Temperature: Gas turbines operate at higher temperatures compared to steam turbines, leading to increased thermal stress on the turbine blades.
- Erosion: The high-velocity gases in gas turbines can cause erosion of turbine blades over time, particularly in the leading edge regions.
- Oxidation: Gas turbine blades can experience oxidation due to exposure to high-temperature combustion gases, which may require protective coatings.
- Vibration: Gas turbines can produce higher levels of vibration, which can affect the fatigue life of turbine blades if not properly controlled.
- Fouling: The combustion process in gas turbines can result in the deposition of contaminants on turbine blades, leading to reduced efficiency and performance.

Steam Turbines:

- Steam turbines are susceptible to moisture damage, which can result in erosion, corrosion, and water droplets impinging on the turbine blades.
- Blade Deposits: The aerodynamics and efficiency of the blades can be impacted by the accumulation of minerals, salts, or impurities carried by the steam in steam turbines.

- Stress Corrosion Cracking: The combination of high temperatures, mechanical stress, and moisture can lead to stress corrosion cracking in steam turbines.
- Thermal cycling can lead to blade damage from thermal fatigue in steam turbines, as they undergo thermal cycling during startup and shutdown.
- Condensate Impingement: Surface erosion and damage can result from condensate droplets impinging on steam turbine blades.

In summary, while both gas turbines and steam turbines have unique effects on turbine blades, gas turbines are more prone to high-temperature-related issues like thermal stress, erosion, and oxidation, while steam turbines are affected by moisture-related problems such as erosion, corrosion, and blade deposits. For instance, in a case study regarding a failing steam turbine blade, the break manifested at the fillet when the tang split. Corrosion between the bottom surface of the tang and slot rotor disc caused the blade to fail. Corrosion fatigue caused the fracture at the tang, and stress corrosion cracking caused the crack at the fillet for the blade with broken tang. shows Fig.10 and 11. [23].

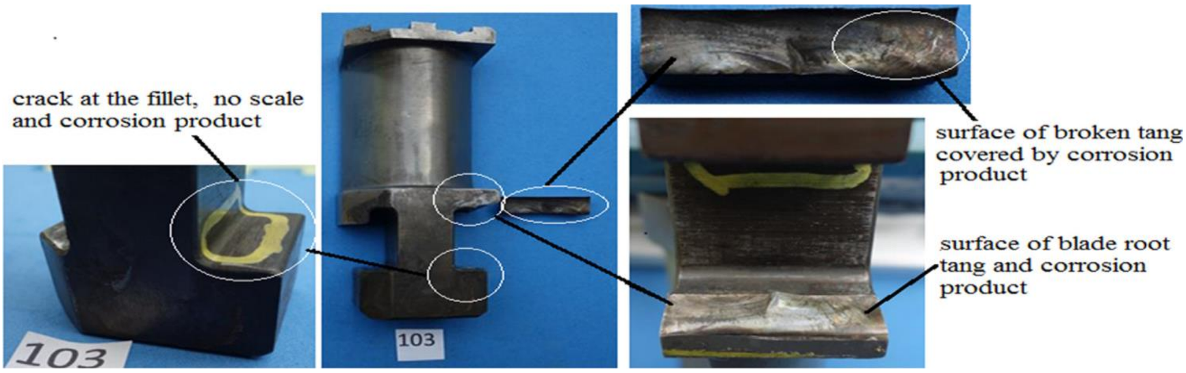


FIGURE 10. - Blade failure with a cracked and shattered tang happened at the fillet in steam turbine.

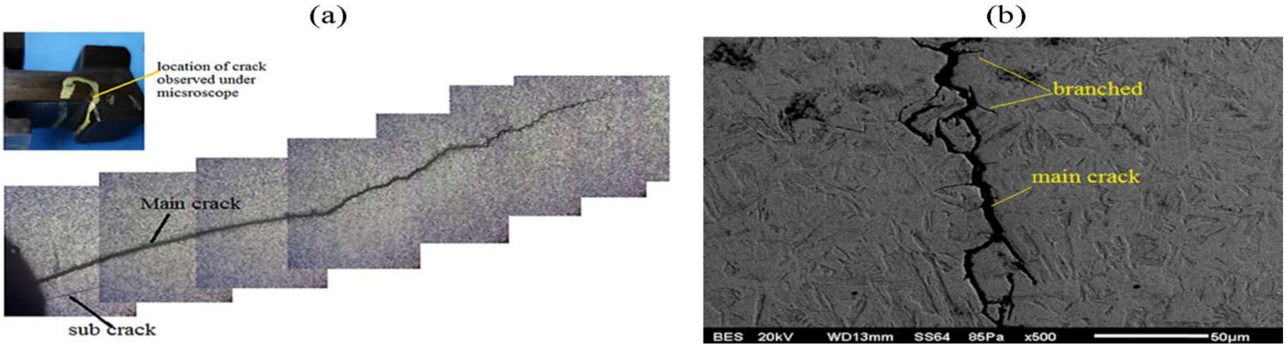


FIGURE 11. - An optical view of a blade fillet displaying a fracture from the surface leading to the blade root's bottom and (b) a branching crack discovered using a scanning electron microscope in steam turbine

2.4 CYCLIC OF STEAM TURBINE WORKING

The working principle of a steam turbine involves the cyclic process of converting the energy of high-pressure steam into rotational mechanical energy. Here's a simplified overview of the cyclic process [22]:

1. Expansion: High-pressure steam enters the turbine through steam inlets, and its energy is converted into kinetic energy as it passes through a series of stationary nozzles. These nozzles accelerate the steam, creating a high-velocity steam jet.

2. Impulse Stage: The high-velocity steam jet strikes the blades of the turbine rotor, known as the impulse blades. The change in momentum of the steam causes the rotor to start rotating.

3. Pressure Stage: After passing through the impulse stage, the steam enters a series of moving blades, known as the pressure blades. These blades are curved, and as the steam flows over them, they exert a pressure force on the blades, further transferring energy to the rotor.

4. Expansion and Condensation: The steam expands as it passes through the pressure blades, losing pressure and temperature. At the end of the expansion process, the low-pressure and low-temperature steam is exhausted from the turbine.

5. Condenser: The expelled steam is sent to a condenser, where a cooling medium, like seawater or air, causes it to condense into water. The latent heat in the steam can be effectively removed thanks to this condensation.

6. Pump: The condensed water is then pumped back to the boiler to be heated again and converted into steam. This completes the cycle, and the process repeats.

The cyclic process of a steam turbine allows for continuous power generation by utilizing the energy of high-pressure steam and converting it into rotational mechanical energy.

In general, a steam turbine is more effective at converting thermal energy into mechanical energy, whereas a gas turbine requires energy uptime and responses quickly to fluctuations in energy demand.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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