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Case study: Investigation of the fracture of low pressure steam turbine blade

Jassim Farij Thijel
PhD. applied mechanics
Midland Refineries Company – Daura refinery – Ministry of Oil - Baghdad – Iraq

Mudher Al-hafidh
MSc. Manufacturing engineering
Midland Refineries Company – Daura refinery – Ministry of Oil – Baghdad – Iraq

Husam A. Abdul-Husain
PhD. applied mechanics
Midland Refineries Company – Daura refinery – Ministry of Oil - Baghdad – Iraq

ABSTRACT
Investigation in the fracture of low-pressure last stage turbine blade of 1.7 MW steam turbine which drives hydrogen compressor in Daura refinery- Baghdad- Iraq has been done to determine the reasons for this failure. The investigation has been performed in three ways: visual, mechanical, and chemical tests. The visual test showed pitting in the leading edge resulted from erosion-corrosion and these pittings had generated a crack that propagated and caused the fracture of the blade. Besides, mechanical tests showed an increase in material hardness and reduction in ultimate tensile stress and yield stress which reduced the strength of the material and made it more susceptible to fracture. Finally, the chemical test and microstructure showed that there is no change in the microstructure and chemical composition of blade alloy.

KEYWORDS: *LP turbine blade, Steam turbine, X20Cr13, Pitting, Crack propagation, Blade fracture.*

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I. INTRODUCTION

Steam turbine blades are critical components that undergo continuous impulse due to the jet of steam. Researches showed that low-pressure stages are more susceptive to failure than mid-stages and high-pressure stages [1,2]. The steam turbine blade could be considered as the heart of the turbine as it converts the thermal energy to kinematic energy and it is subjected to centrifugal force (F_c) that is resulted from rotation as well as bending force (F_b) which comes from steam. There are lots of reasons that could cause the failure of steam turbine blades. Some of the reasons are high stresses, high vibration, material failure, high temperature, environmental effects, and operating conditions. The most common failure occurs due to periodic load stress in the blades that happen because of force fluctuation at the blade airfoil region [3].

The investigation was undertake to know the reasons for blade fracture in a 1.7 MW steam turbine which rotates at (10,000 rpm) after (60,000 hr) of work. It works as a driver for centrifugal compressor namely K201 which compresses hydrogen in power former unit (2) in Daura refinery- Baghdad – Iraq. The failure occurred at one blade in the last stage (12^{th} stage) low pressure (LP) steam turbine. The fracture is located at (13 mm) from the root of the blade which is (95 mm) long as shown in figure (1). The material of the blade is X20Cr13 tempered martensitic chrome alloy steel. In addition, visual inspection showed that the guard wire which holds 15 blades from the top has been dislocated.

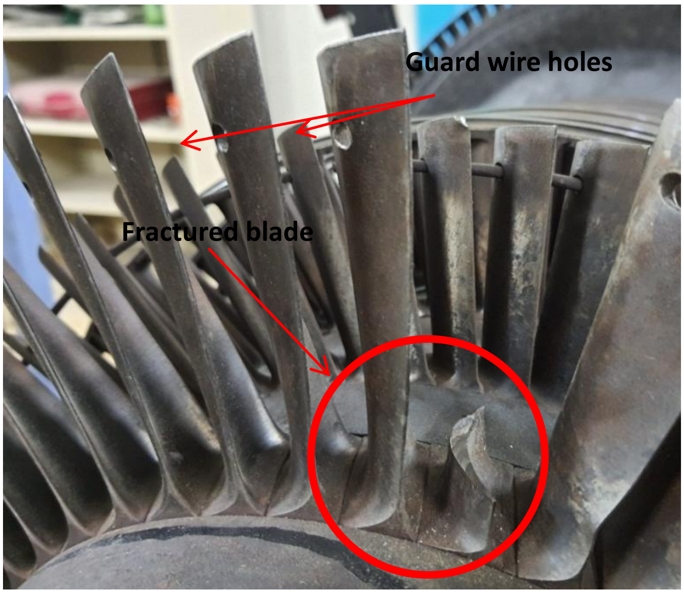


Figure (1) LP last stage turbine blade failure.

As a temporary solution to avoid a long shutdown of the unit and as there is no spare rotor, another blade has been cut 180^o from the broken blade. Besides, a new wire guard has been installed and dynamic balance has been done to return the rotor to the service immediately. However, the broken blade area and the cut blade have been inspected to specify the reasons for this failure and to inspect the whole stage. The inspection included visual tests, chemical, and mechanical properties analysis to determine the reasons for the failure which caused a high vibration in the turbine and emergency shutdown in the equipment.

II. LITERATURE REVIEW

As steam turbines are widely used in refineries and thermal power stations, many researchers had been focusing on turbine blade failures in multi-stages turbines in the last 60 years. Hariprasad, et.al, analyzed the failure of the final stage LP steam turbine using finite element modeling technique and concluded that the failure in blades can occur even if major advances are made in designing of the blade. This is due to the complexity of blade behavior which is affected by many factors such as temperature, vibration, stresses material blade design, and maintenance effect [3]. Kumar and Viswanath studied a modified blade design that could resist the effects of creep-inducing temperature, stresses, and corrosive chemicals. They founded that the new design improved the efficiency of the turbine and reduces the stresses. However, they showed that blades are susceptible to high stresses and forces under normal operation [2].

Kasl et.al, used fractographic and material analysis methods and they suggested that fracture in the LP steam turbine blade can take place due to corrosion fatigue that initiates from corrosion pits [1]. Goutam et.al, had investigated the (LP) turbine blade failure of a 220 MW in a thermal power plant experimentally by using chemical analysis and scanning electron microscope images. They noticed a pitting and grooves on the turbine blade surface. Also, a Silicon phase was detected on the blade surface. They suggested that failure occurred due to corrosion-fatigue [4]. Another turbine blade failure in a thermal power plant of 350 MW steam turbines has been investigated by Kubiak et.al,. They used the finite element modeling analysis to find the natural frequency of the blade and to determine the stress distribution in the root area. They concluded that the cause of crack initiation is due to stress concentration in the blade root. Furthermore, the metallurgical analysis showed that crack was propagated by corrosion-fatigue [5].

Wie-Ze et.al, investigated the failure analysis of the final stage blade in the steam turbine experimentally. Microstructure and mechanical tests have been done on the surface of the fracture. They suggested that fatigue has been accelerated by corrosion and caused the fracture of the blade after 13200 hr of service [6].

Another study concluded that high-cycle fatigue (HCF) is a cause of turbine blade failure and this happens due to acceleration and deceleration during startups and shutdowns as it passes through one of the natural frequencies of the turbine blade [7]. Low cycle fatigue (LCF) has been also studied to determine the fatigue life at different temperatures. The results showed that the stress range decreases and plastic deformation increase with the increase in temperature [8].

Finally, many studies showed that the low pressure (LP) turbine blades are critical components in both steam and gas turbines and they are more susceptible to failure than other stages [8,9,10]. Researchers concluded that blade life is influenced by corrosion failure [11,12], fatigue-creep failures [13,14] and fretting fatigue failures [15,16].

III. EXPERIMENTAL DETAIL

The fracture of the broken blade has been located at (13mm) from the root of a 95mm long blade of the final stage (12th) low-pressure steam turbine. The turbine running time is about (60,000 hr). The material of the blade is X20Cr13 martensitic chrome alloy steel which its chemical composition is shown in table (1).

Table (1) Chemical composition of X20Cr13

Fe %	Cr %	Mn %	Si %	S %	P %	C %
84.27	12-14	<1.5	<1	<0.03	<0.04	0.16-0.25

Visual inspection has been performed to determine any marks or pitting that could appear on the blade surface which could indicate erosion or mechanical failure. A penetration test has also been done to reveal further cracks on other blades.

Mechanical properties of the fractured blade have been also investigated to determine the change in material properties. Measuring the hardness of the material and performing a tensile test to the material specimen. The results have been compared with the original properties of the material.

Chemical composition has been analyzed in the fracture region to determine the change in elements. Besides, microstructure analysis has been done to the material blade to determine the change in material microstructure and to inspect the surface of the blade.

IV. RESULTS AND DISCUSSION

4.1 Visual inspection

Visual inspection revealed that a crack has been propagated from the attack angle of the blade. On the area of broken blade beach marks and pitting on the blade attack angle and broken surface have been noticed as shown in figure (2). The guard wire holds 15 blades in the stage which consists of 50 blades noticed to be missing and dislocated from its place.

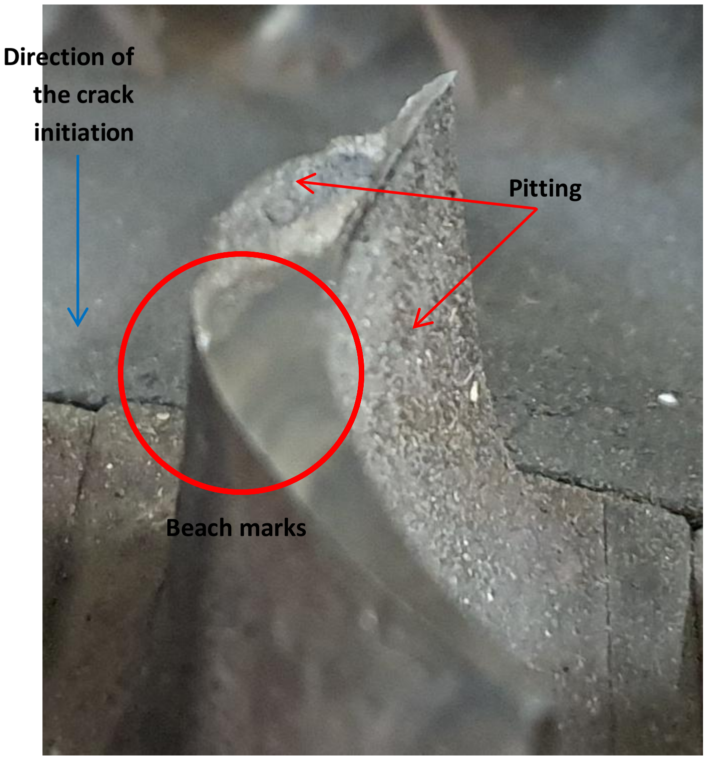


Figure (2) Beach mark on broken surface

Also, deep pitting has been noticed on all blades of the 12th (last stage) of the turbine along the leading edge of the blades at the suction surface (figure 3). These pitting are a result of erosion-corrosion on the blade surface. This could be an indication that crack has been propagated from the pitting area that caused stress corrosion cracking (SCC) which is common in low-pressure turbine blades [12].

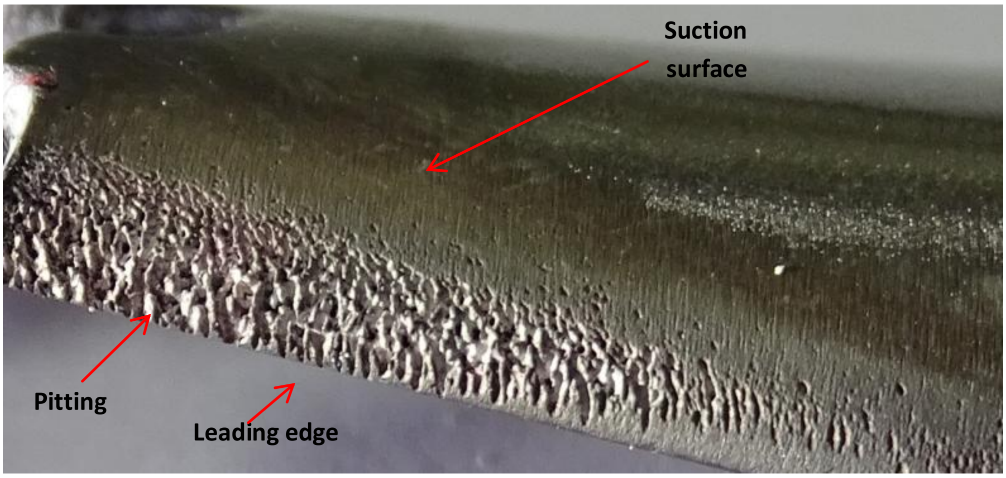


Figure (3) Pitting along the leading edge turbine blade.

Furthermore, penetration test has been performed to inspect blade for other cracks that may exist. The tests showed no other cracks has been existed on the un-fractured blades in the last stage of the steam turbine as shown in figure (4).

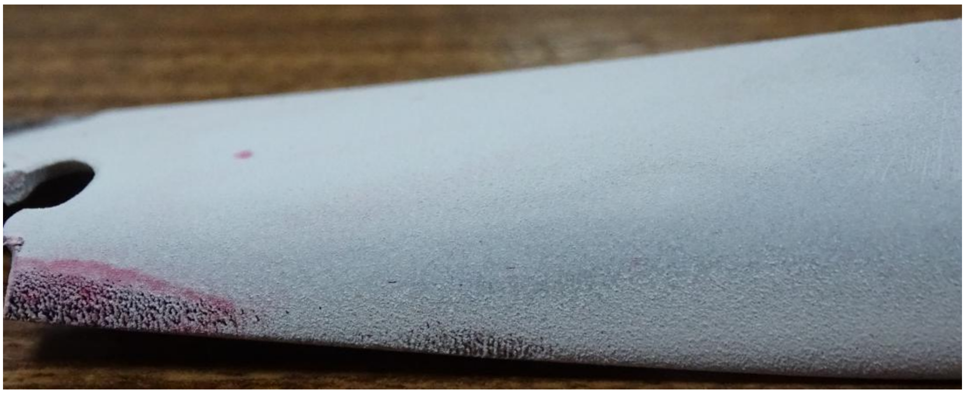


Figure (4) penetration test show no further cracks on blade.

4.2 Mechanical tests

Hardness test has been performed on the blade at pitting area and root area. The results of hardness showed that the hardness has been increased to 309 HB whereas the standard hardness of X20Cr13 tempered martensitic stainless steel is 225 HB. The increase in hardness by 37% increases the brittleness and reduces ductility of material which would be more liable to fracture due to cyclic stress that the turbine blades are subjected to it.

Tensile test results showed that there is a noticeable decline in ultimate, yield, and feature stress. The ultimate tensile stress has been dropped from 700 Mpa to 500 Mpa (reduction 28%) while the yield stress has been decreased from 500 Mpa to 385 Mpa (reduction 23%) figure (5).

This significant deterioration in mechanical properties could be due to long working hours which is 60,000 hrs as the steam turbine blades are susceptible to high temperature and stress levels [14]. In addition, turbine blades are subjected to pressure fluctuation due to the flow of steam which causes vibratory stress and these fluctuations in loads will result in high-stress concentrations especially in blade root in addition to pitting that initiate the crack [3,18].

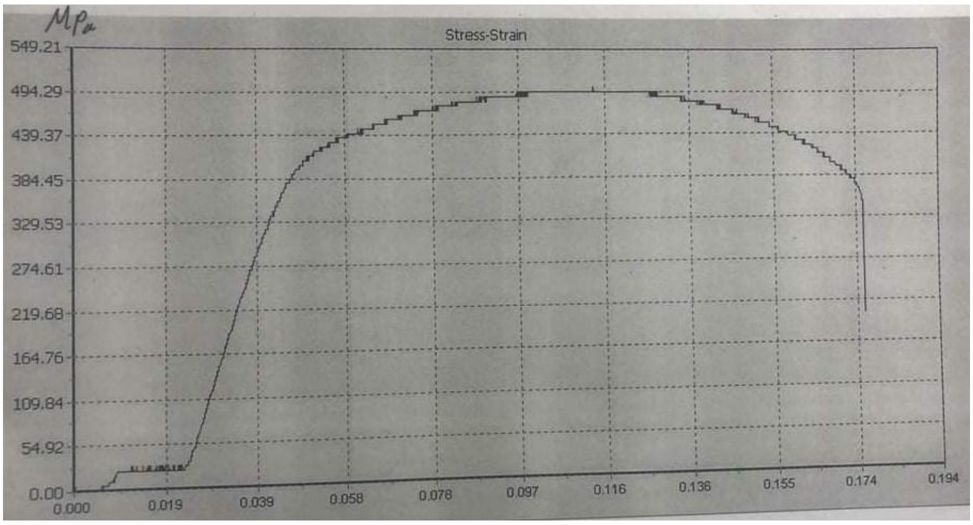


Figure (5) Stress-strain curve for blade material

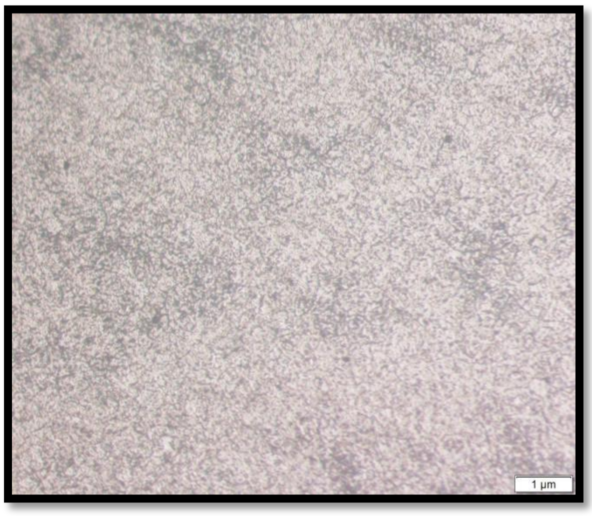
4.3 Chemical analysis and microstructure

Chemical composition analysis showed no noticeable change in chemical composition compared with standard X20Cr13 tempered martensitic stainless steel as shown in table (2).

Table (2) Chemical composition of X20Cr13

Fe %	Cr %	Mn %	Si %	S %	P %	C %	
85.16	12	0.44	0.5	0.013	0.04	0.25	Tested
84.27	12-14	<1.5	<1	<0.03	<0.04	0.16-0.25	Standard

Regarding the microstructure investigation, two specimens had been inspected one on the pitting region and the other on the blade root region. Optical micrographs for both polished specimens showed normal homogeneous microstructure with no evidence of degradation in microstructure of the X20Cr13 martensitic stainless steel as shown in figure (6).



(a) (b)

Figure (6) Optical micrograph at 600x of blade material (a) root region (b) pitting region

V. CONCLUSIONS

Visual test, mechanical and chemical analysis have been performed for the last stage turbine blade to determine the reasons for blade fracture of 1.7 Mw steam turbine. The conclusions are as follows:

1. The visual test showed pitting due to erosion-corrosion on the leading edge on all last stage turbine blades. These pitting led to crack initiation and propagation as beach marks showed that the crack initiated from the leading edge and propagated to the trailing edge and caused the blade fracture.

2. Mechanical tests revealed that the hardness of the material has been increased which caused the material to be more brittle while ultimate tensile and yield stresses have been decreased which made the material more susceptible to failure due to this deterioration in mechanical properties.
3. Chemical test and microstructure showed that there is no difference in the microstructure of the material compared with the material standard which means that there is no material defect that caused the blade fracture.

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