

## FAILURE OF GAS TURBINE CONE BURNER BY CARBURIZATION

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### **Abstract**

*Gas turbine for a power plant has 72 pieces of cone burner in its combustion chamber. High-speed diesel oil (HSD) is used as fuel to produce 130 MW of power at 3,000 rpm. The maximum temperature at the turbine inlet is estimated about 1087°C and at the outlet is between 400-540°C. Sixty percent of the cone burner failed repetitively at one side of the tip-end after 6,000 hours of service. The refurbished cone burner has to be replaced by a new one after 18,000 of service-hours. The cone burner material is cast Hastelloy-X (nickel based alloys). Metallurgical analyses by microstructural observation using optical and scanning electron microscopes, and energy dispersive spectroscope have been performed to observe the change in burner microstructure. Thermodynamics analysis has been performed to obtain temperature distribution around the failed section. Two failed cone burners have been examined; cone burner that has not been repaired, and that has been repaired twice.*

*Thermodynamics analysis result shown that the temperature around the failed section is between 897 to 1087°C. Microstructure of the good part, far from the failed section, consists of cast structure of austenite matrix and fine carbide particles. Severe carbide precipitation and growth was observed on the failed section even the nominal carbon content in material is only 0.10% (max.). Severe carbide precipitation occurred because of carbon ingress from the environment (carburization) which combines with carbide forming elements in material (chromium, molybdenum, and tungsten). As a result, the corrosion and oxidation resistance of material decreased significantly after long time exposure at high temperature that led to oxidation, thinning, and failure of the cone burner tip. Failure only localized on one side of the tip-edge, therefore refurbishment by welding and coating can be performed to extend the life cycle of cone burner. The current examination results shows that the replacement cycle is not only limited to 18,000 hours but can also be extended to 48,000 hours.*

**Keywords:** *Gas turbine, cone burner, Hastelloy-X, carburization, microstructure, carbide, thermodynamic simulation*

### **1. Introduction**

Gas turbine is used extensively to produce electric power because it can be synchronized with the system in short time to supply and distribute electric power to the consumers. The optimum operation performance is the main objectives of operation and maintenance in a power plant. The

turbine efficiency will decrease and components failure will occur when the optimum operating condition cannot be achieved that led to increasing operation and maintenance cost. This paper will discuss a failure of a cone burner in a gas turbine engine of a power plant and remedial action that has been taken to increase engine reliability.

The gas turbine engine (133.8 MW, 3000 rpm) was commissioned in 1997 and has 72 annulus burners. High-speed diesel oil fuel is injected into the combustion chamber and at the same time, water is also injected through oil lance tip nozzle. The purpose of water injection is to soften the flame and reduced the emission (NOx), and to increase the fuel flow rate that will shift the flame forward. The inhomogeneity of water and fuel distribution will result in inhomogeneous combustion that can damage the burners. Fig. 1 shows the schematic of combustion chamber and the geometry of the annulus burner.

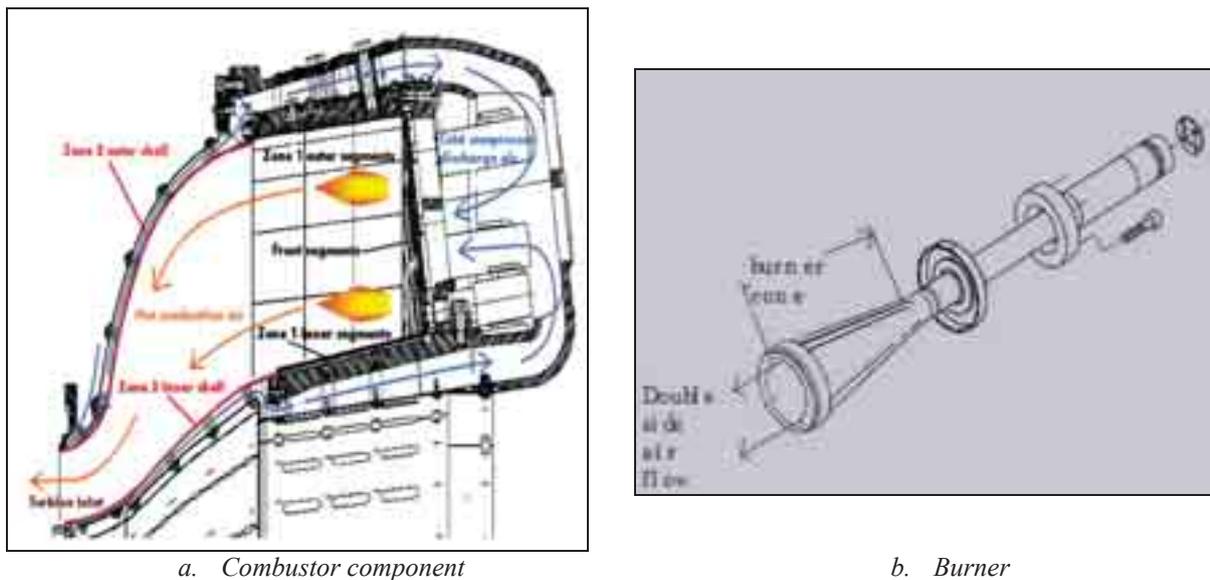


Fig. 1. Annular combustor in gas turbine engine [4]

Periodic maintenance schedule recommended by the Original Engine Manufacturer (OEM) is 24,000 equivalent operating hours (EOH), however the recommended service hours cannot be achieved because the hot gas path especially the cone burners were failed every 6,000 EOH even the fuel and water flow have been adjusted and optimized accordingly. Sixty percent of the burner cones failed and has to be replaced with the new one after 18,000 EOH instead of 48,000 EOH as stated in the engine manual. Fig. 2 shows the comparison between good and failed cone burner. The exposed surface of a new cone burner was coated by thermal spray to prevent direct contact with the combustion gas. Failure occurred on the edge side (Fig. 2b). The burner life was extended by welding repair followed by coating of the damaged section for every 6,000 EOH.

Cone burner material is nickel-based alloy Hastelloy-X and the chemical composition is shown in Tab. 1. Melting point of Hastelloy-X is between 1250-1355°C, incipient melting started at 1250°C, and carburization occurred at 650°C and above [1]. High temperature strengthening was obtained from austenite matrix, solid solution hardening, and carbides strengthening. Chromium is present for corrosion and oxidation resistance of material.

Tab. 1. Standard Chemical Composition of Hastelloy-X (wt. %) [2]

Ni	Cr	Fe	Mo	Co	W	Si	Mn	P	S	B	C
Bal.	20.5-23.0	17.0-20.0	8.0-10.0	0.50-2.50	0.20-1.00	1.0 max.	1.0 max.	0.04 max.	0.03 max.	0.01 max.	0.1 max.



Fig. 2. Comparison between good and failed cone burners

Thermodynamic analysis by simulation of combustion in the combustion chamber has been performed by Putra [5] using Fluent software to obtain temperature distribution and the maximum temperature in the cone burner. The simulation result shows that the maximum temperature on the flame is 2215°C, on the burner wall is between 897 to 1087°C, and on the burner outlet is 1341°C. There is a discrepancy between simulation result and the actual burner outlet temperature (1070°C), therefore correction to the simulation result of burner wall temperature has been introduced using the actual burner outlet temperature as a reference. The corrected maximum burner wall temperature is estimated between 746 to 902°C.

This paper will present the result of metallurgical analysis performed to obtain the root cause of cone burner failure. The analysis results will be used as a guidance in planning future maintenance and recommend the new replacement cycle.

## 2. Examination Procedures

Two failed cone burners, cone A and cone B, were examined in the laboratory to find out the root cause of failure. Cone A has been used for 6,000 EOH and has not been repaired, cone B has been in service for 18,000 EOH and has been repaired twice.

Chemical composition of the cone burners were examined using optical emission spectroscopy (OES). Microstructure examinations were conducted using optical and scanning electron microscopes (SEM). Microstructural observations in the cross section were performed on several samples taken from the damage, and from the lowest temperature sections. Observation was also conducted on the material for repair. The microstructure from the lowest temperature section will represent the microstructure of the new material. Chemical composition of carbides was examined by energy dispersive spectroscopy (EDS).

## 3. Examination Results and Analysis

### 3.1. Chemical Composition

Chemical composition of cone burners is shown in Tab. 2. The cone burner materials and material for repair fulfil Hastelloy-X specification. Boron (B) content cannot be examined because the OES is not equipped with boron detector.

Tab. 2. Chemical Composition of Cone Burners (wt.%)

Element	Cone A	Cone B	Material for Repair
Ni	Bal.	Bal.	Bal.
Cr	20.87	22.08	21.02
Fe	18.60	18.99	18.34
Mo	7.29	6.93	8.07
Co	1.35	1.32	1.82
W	0.29	0.24	0.10
Si	0.60	0.45	0
Mn	0.69	0.65	0.62
P	0.020	0.023	0.03
S	0.022	0.018	0.025
C	0.056	0.048	0.045
B	ND	ND	ND

ND : Not detected

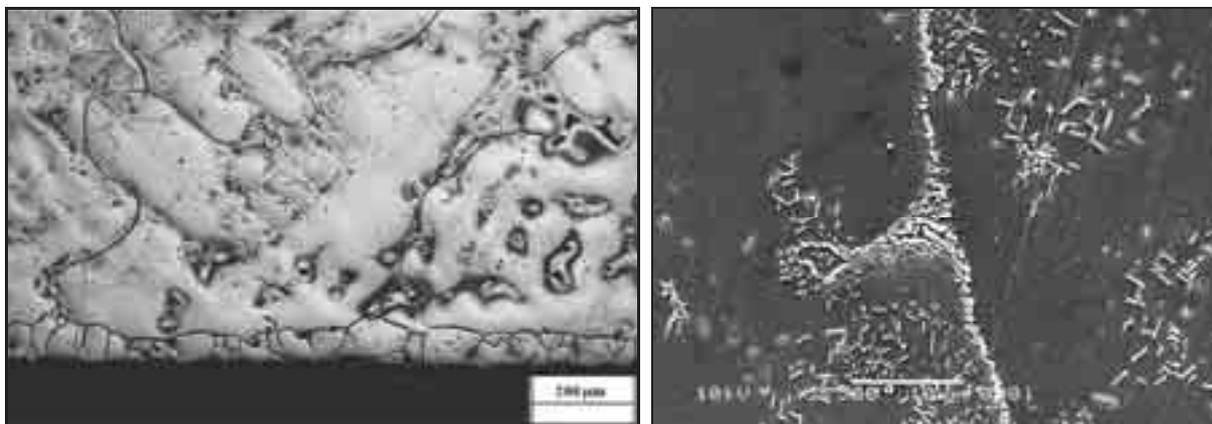
### 3.2. Microstructure

Microstructure of cone A at the lowest temperature section is shown Fig. 3. The microstructure consists of austenitic matrix and fine carbide distribution along grain boundaries and inside the grain (Fig. 3b). Cone burner was manufactured by casting as indicated by the irregular and elongated grains geometry.

Figure 4 shows the microstructure of cone B from the lowest temperature section. Cone B is also manufactured by casting as shown by the geometry of the grain. Carbide precipitates were evident along grain boundaries and inside the grain. Carbide volume fraction in cone B is much higher than that of cone A because cone B has been exposed longer than cone A. Carbide precipitation will increased with higher exposure (aging) time.

The fresh material for repair is not available because the repaired process was done by outside workshop, therefore the observation has to be done on repaired section at the least attack part. The microstructure consists of equiaxed austenitic matrix grains (Fig. 5). Material for repair is not cast material but hot rolled plate under solution-annealed condition. Fine carbide precipitates in material are due to the effect of exposure during service.

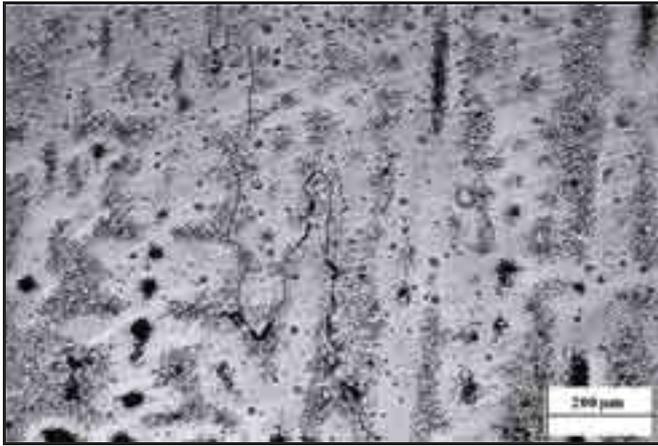
Microstructures of the damage cone burner are shown in Fig. 6 to 8. Carbide precipitates volume fraction increase significantly even the maximum carbon content in Hastelloy X is 0.1%, therefore carbon in the combustion gas diffused into material (carburization) during the service. Carburization occurred because the service temperature is above 650°C and carbon potential in combustion gas is high.



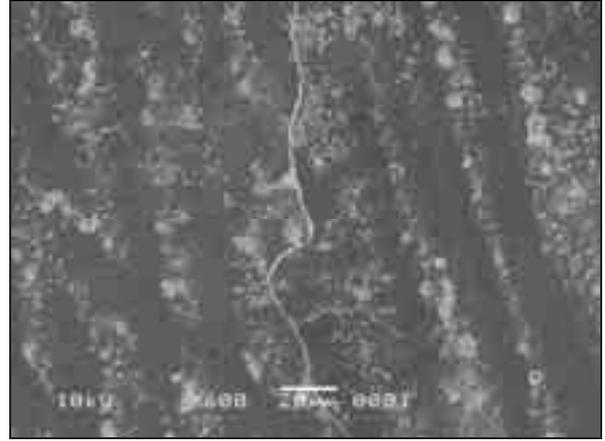
a. Optical micrograph

b. SEM micrograph

Fig. 3. Microstructure of cone A, lowest temperature section

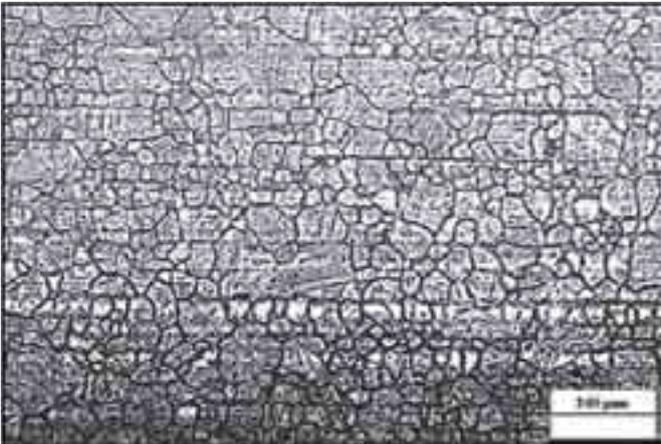


a. Optical micrograph

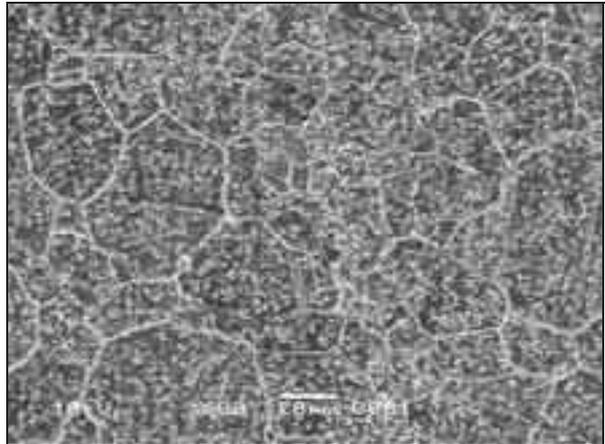


b. SEM micrograph

Fig. 4. Microstructure of cone B, lowest temperature section



a) Optical micrograph



b) SEM micrograph

Fig. 5. Microstructure of material for repaired

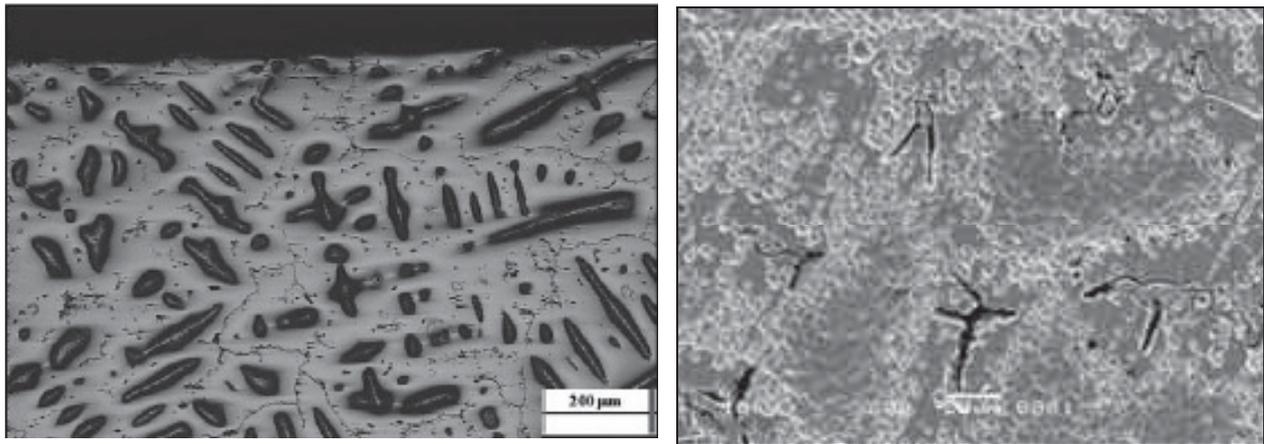


a) Optical micrograph



b) SEM micrograph

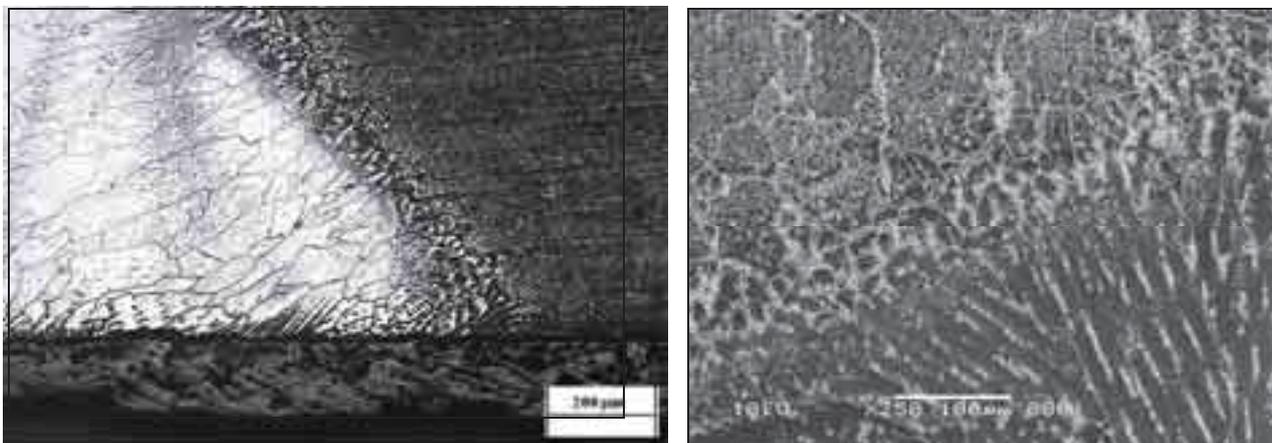
Fig. 6. Microstructure of damaged cone A



a) Optical micrograph

b) SEM micrograph

Fig. 7. Microstructure of damaged cone B



a) Optical micrograph

b) SEM micrograph

Fig. 8. Microstructure of damaged material for repaired

Figure 8 shows the microstructure at the interface between cone burner base metal (bright) and repaired material (dark). Carburization in repaired material is much severe compared to that of base metal (Fig. 8a) because carburization occurred through grain boundary diffusion [3]. Grain boundary diffusion rate of carbon in repaired material is much higher than the base metal because the repaired material has much finer grain size. Volume diffusion dominant in the near surface region.

### 3.3. Carbides Composition

Carbides in cone burner material consist of primary and secondary carbides. Primary carbides are formed during casting while secondary carbides precipitate and growth during service (aging). Two types of carbides were examined, fine, and coarse carbides (Fig. 6b). Summary of examination is shown in Tab. 3. Aluminum in the measurement result is the trace of alumina particle for polishing.

Detail examinations of carbide in Hastelloy X after carburization have been done by Shindo *et. al* [6]. The majority of carbide in the grain boundaries and inside the grain is  $M_6C$  type. High amount of molybdenum in fine carbide indicates that its composition is close to molybdenum

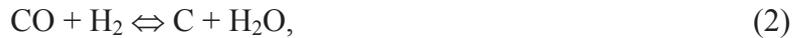
carbide ( $\text{Mo}_6\text{C}$ ). Coarse carbide is more complex because the carbide-forming element is distributed and there is no dominant element. Further examination using x-ray diffraction is required to verify the coarse carbide type.

*Tab. 3. Chemical Composition of Carbides (wt.%)*

Element	Fine Carbide	Coarse Carbide
C	9.19	38.33
Al	0.24	0.50
Si	3.44	1.06
Cr	16.06	7.55
Fe	1.40	5.77
Co	1.0	4.56
Ni	30.25	37.83
Mo	36.26	3.50
W	2.16	0.90

#### 4. Failure Mechanisms

Failure of cone burners is due to the ingress of carbon (carburization) from the combustion gas into material above  $650^\circ\text{C}$ . The origin of carbon can be traced through the dissociation of water vapour at  $1527^\circ\text{C}$ , followed by carbon formation as a product of reaction between carbon monoxide and hydrogen gas. Carbon monoxide itself dissociate to carbon and oxygen. The complete sequence of chemical reaction is shown in the following :



Strong carbide former elements (Cr, Mo, W, Fe) in Hastelloy X will tight the ingress carbon to form carbides along the grain boundaries and within the grain. Chromium carbide formation will reduce the chromium content in the matrix, hence the susceptibility of material to oxidation increases. The oxidation of metal (M) at high temperature will also supply additional carbon to material following the reaction :



It is clear that carburization of cone burner not only induced the formation of brittle carbides but also sacrifice corrosion and oxidation resistance, room temperature ductility, and resistance to thermal shock . Fortunately, carburization attack occurred localized around the edge end of the cone burner, there is no significant carbon ingress on the other location. Material for repair is carburized more easily compared to that of cone burner material because it has much finer grain size.

#### 5. Summary and Conclusions

The root cause of cone burner failure is carburization by the ingress of carbon in combustion gas into material. Carbon in combustion gas originated from the incomplete combustion even the operating parameters have been optimized. It is believed that the quality of high-speed diesel oil is the main cause of failure and the Company has to accept the fact that oil quality of each batch is different and the discrepancy could be very significant.

Thermal spray coating application on the exposed surface is the smart solution to prevent carburization but preservation of coating integrity at the surface edge is very difficult. Once the

coating on the edge breaks, the fresh surface is exposed to the carbon environment and initiates the carburization attack. Welding repair has successfully extend cone burner life but longer life extension can be expected if material for repair has a coarse elongated grains similar to that of cone burner material.

Carburization of cone burners occurred localized around the repaired section. There is no significant carbon ingress in the other section, therefore, the replacement cycle is not limited up to 18,000 EOH but can be extended to 48,000 EOH. Metallurgical analysis after each repair cycle (6,000 EOH) is required to evaluate the carburization effect in cone burner and establish its integrity status for future service.

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