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An investigation on a failed turbocharger turbine blade

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ABSTRACT

A failure analysis of a turbocharger blade made of Ni base superalloy is presented in this case study. Localized remelting of eutectic structure due to overheating during operating is the main cause for the failure. The γ' precipitates at the blade's root, cold reference zone are fine compared to the coarse γ' particles found close to the crack area. Micro-cracks initiated in interdendritic regions due to the reduction of strength in these areas because of overheating. The weakened microstructure and mechanical stresses caused by vibration, centrifugal forces and bending moments caused fatigue as evidence by, beach marks and tear ridges on the fracture surface. The fatigue failure is the prevailing mechanism of fracture failure in airfoil section.

KEYWORDS

Turbocharger;
Blades;
Failure analysis;
Overheating;
Cracks;
Fatigue.

INTRODUCTION

During service of a turbocharger, an abnormal sound was heard. The engine was shut down and was carefully inspected. The investigation started with a thorough visual inspection of the turbocharger and blades surfaces. It was found that the turboblades had been damaged. All the turboblades were disassembled from the turbine. Some of the failed and unfailed blades were selected for further investigation. These blades served for 3 months after overhauling of the turbocharger. Each turbocharger has a one stage turbine that contains 47 turboblades.

Observation

Figure 1 shows a failed blade that entirely separated from the airfoil section at a position 12mm away from the platform. The fracture surface of this blade is perpendicular to the longitudinal axis of the turbine blade.

One of the broken turbo blades was found to contain a crack, which was also located at about 12mm above the platform. This crack occurred on the convex side of the airfoil, figure 2. The similarity in the location of the fracture in the blade shown in figure 1 and the crack shown in figure 2 suggests that the turbine blades faced similar conditions which caused the initiation and propagation of the crack.

Figure 3 shows a turbine blade broken on the tip at the leading edge, left-upper, of the airfoil. Moreover, the right-upper tip of the airfoil, trailing edge, was deformed. A few turbo blades were found to be completely sound with no signs of any damage.

Sequence of the fracture

From the above observation, the sequence of the damage for the turboblades starts first with the complete separation of the airfoil part of the blade in figuer 1, at 12mm above the platform. This separated airfoil part collided at high speed the other blades in the turbocharger. The fragments, produced from the previous events, with accelerated velocity would hit other blades leading to destruction and deformation of these blades.

MATERIALS CHARACTERIZATION

Chemical analysis

The chemical analysis of the blade material was determined by energy dispersive spectrometer (EDS). It was found that the material of the failed blade is a Ni base superalloy which contains the following elements, Si, Mn, Al, Ti, Cr and Mo[1-6].

Ni base superalloys are widely used for high performance applications such as disks and blades of either aircraft engines or land-based gas turbines[7,8].

Microstructure

Optical microscope

As shown in figure 4, the turbo blade, a cast polycrystalline Ni base superalloy, has a denderitic structure. In this figure, the primary and secondary dendrite arm spacing can be easily recognized.

Ni base superalloys are strengthened through the precipitation γ' phase, $Ni_3(Al, Ti)$ in a fcc γ-Ni matrix[9]. The microstructure of the failed turbo blade is composed of γ nickel-rich solid solution, fine and dispersed γ' precipitates, eutectic γ and carbides, figure 5[10,11]. This is the ideal microstructure with a fine ordered quasi-cubic precipitate of γ' that should be obtained during manufacture to optimize high temperature strength. Carbides are located in the interdendritic regions in round and plate-like shapes, it can be as well found as a network at the grain boundaries of γ matrix, (Figure 6).

The presence of few porosity and shrinkage cavities in the structure of the unfailed blade can be detected; such defects are unlikely to play a major role in the failure of the blades, (Figure 7).

Scanning electron microscope (SEM)

In some interdendritic regions, a high density of plate-like carbides was found, figure 8. These carbides, analyzed by using EDS, were found to consist of Mo, Cr and Ti.

Figure 9 shows the γ' precipitates in γ matrix at the root of the platform section which represent the cold reference zone. The root of the blade is considered as "cold or reference zone" as it is not exposed to the hot combustion gases and microstructural changes are not considerable[12]. Most of γ' precipitates in blade's root are cubic morphology with average cubic edge about 0.45μm.

As shown in figure 10(a) and 10(b) the crack starts on the convex side (suction side) and propagates towards the concave side (pressure side) perpendicular to the blade vertical axis following the degraded structure in interdendritic regions and grain boundaries.

Compared to the γ' precipitates at the blade's root, cold reference zone in figure 9, coarse γ' particles can be found close to the crack area. The abnormal working conditions may elevate operating temperature or due to the fire that had occurred for several times, around the blade airfoil leading to the growth of the γ' and even approaches the solidus temperature of the blade material in shorter time. It can be stated that the sharp corners of the cuboidal γ' precipitates, in cold zone, become more rounded, coalescence and coarsening of γ' can be observed, figure 11.

It is also noted that, some positions in the interdendritic zones were found open as it can be seen in figure 12(a). Moreover, a localized re-melting of eutectic at higher magnification was revealed as well, figure 12(b), leading to degradation of the microstructure and initiation of micro-cracks from the interdendritic regions[13,14]. Micro-cracking preferably occurred in interdendritic regions and the cracks propagated within the interdendritic region to form short cracks on the airfoil surface, figure 13.

Fracture morphology

The fracture surfaces of the failed blade were observed in detail. Beach marks and tear ridges can be found on the fracture surface as shown in figure 14[15-17].

Presence of the over-heat damage structure would considerably decrease fatigue strength of the blade.

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Figure 1 : Broken turbo blade

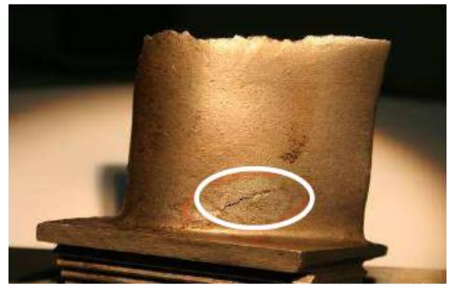


Figure 2 : Crack starts and propagates at the convex side of the airfoil

Figure 3 : Partially broken blade at the tip of the airfoil

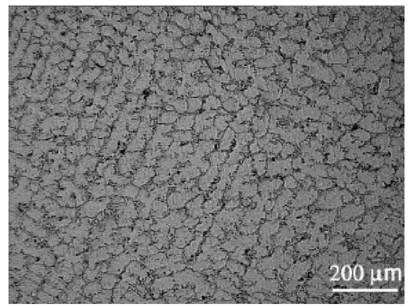


Figure 4 : Denderitic structure of cast Ni base superalloy

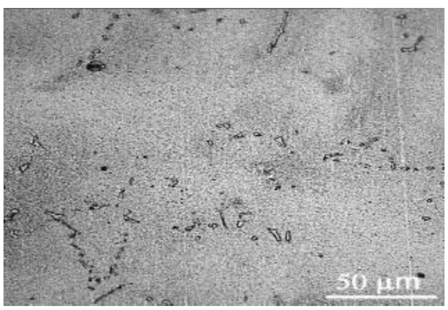


Figure 5 : Microstructure of cast Ni base superalloy

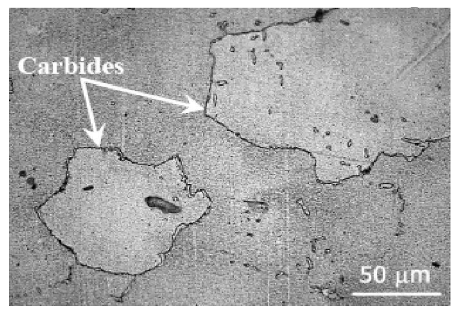


Figure 6 : Carbides network at the grain boundaries of γ matrix

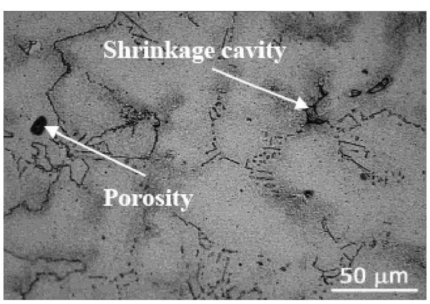


Figure 7 : Porosity and shrinkage cavity presented in the structure

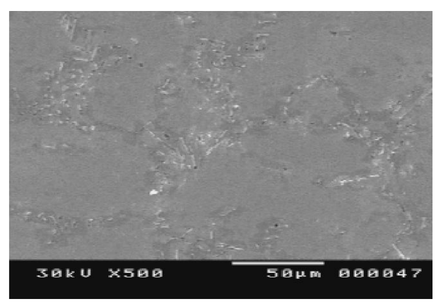


Figure 8 : High density of carbides in interdendritic regions

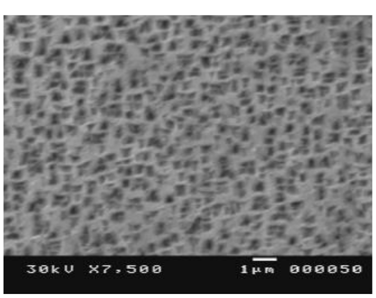


Figure 9 : γ′ precipitates in γ matrix at the root of the platform section

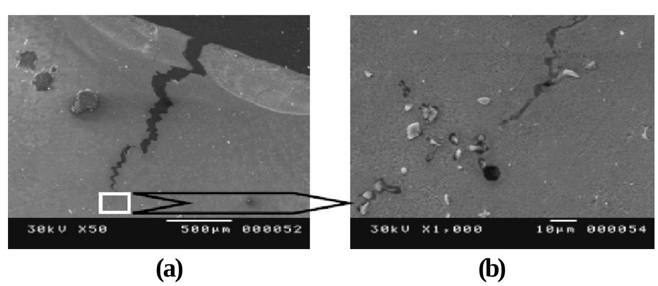


Figure 10 : (a) Crack starts at the convex side of the blade, (b) Crack propagates through the interdendritic region

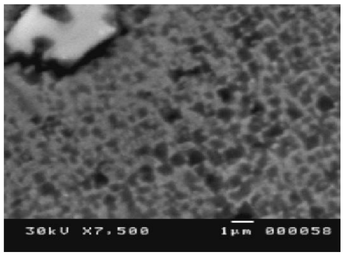
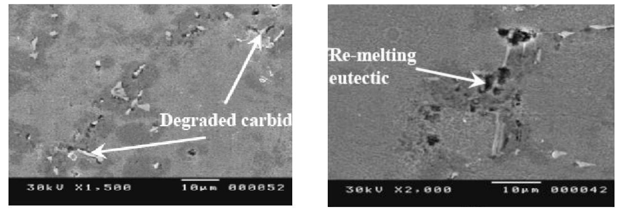


Figure 11 : Coarse γ′ precipitates in γ matrix adjacent to the crack area



(a) (b)

Figure 12 : Re-melting of eutectic γ/γ′ and degraded carbide in interdendritic regions

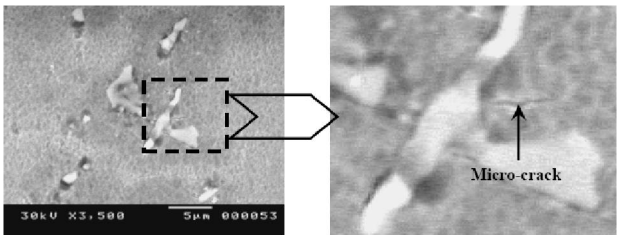
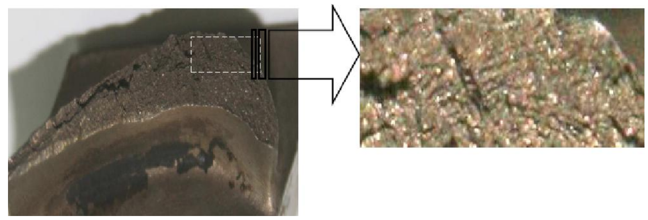
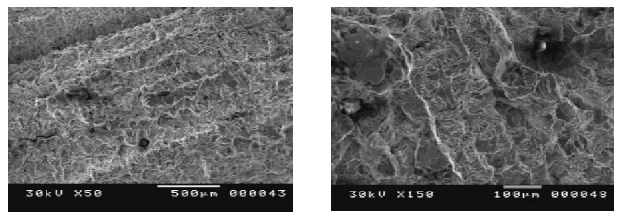


Figure 13 : Micro-crack starts at interdendritic zone



(a)



(b) (c)

Figure 14 : Fracture surface of the failed blade

When gases flowed into concave side of the blade through the leading edge, the surface of the concave side of the blade was subjected to bending tensile stress and hence crack can easily initiate at this region.

CONCLUSIONS

1 The material of the turbine blades used in the turbocharger, under this investigation, is cast Ni base superalloy.

2 The investigation of γ′ precipitates at the fracture surface of the failed blades indicates that the blades have been subjected to very high temperature. This off-design regime resulted from nonuniform temperature distribution.

3 Typically over-heat structure damage had taken place due to localized remelting of the eutectic structure of the failed blades. It is suggested that the operating temperature of the blades had exceeded the specified one leading to over-heat damage.

4 In addition to overheating, fatigue cracking is the prevailing mechanism for the occurrence of the fracture failure in airfoil section.

5 Micro-cracking is initiated in interdendritic regions due to strength reduction because of over-heating. Under centrifugal, vibration and bending stresses, the micro-cracks propagated within the interdendritic region and formed short cracks in the airfoil section. The nearby short cracks with identical orientation converged to form long cracks, and the transverse fracture occurred at the airfoil.

6 The crack starts at the convex side, suction side, and propagates towards the concave side, pressure side, perpendicularly to the vertical axis of the turbine blade.

7 The fragments resulted from the previously fractured blade would hit and damage other blades in the neighborhood.

REFERENCES

[1] M.Farhrmann; Acta Metall., **43**, 1007 **(1995)**.

[2] G.C.Bieber, R.J.Mihalisi; 2nd International Conference on the Strength of Metals and Alloys, Asilomer, ASM, **4**, 1031 **(1970)**.

[3] D.J.Bryant, G.McIntoch; In: R.D.Kissinger, (Eds.,); Superalloys, The Mineral, Metals and Materials Society, 713 **(1996)**.

[4] K.A.Green, J.A.Lemsky, R.M.Gasior; In: R.D.Kissinger, (Eds.,); Superalloys, The Mineral, Metals and Materials Society, 697 **(1996)**.

[5] H.Puschink, G.Zeiler, J.Fladischer, W.Eber, K.H.Keienberg; La Metallurgia Italiana **82**, 473 **(1990)**.

[6] H.Hattori, M.Takekawa, D.U.Furrer, R.J.Noel; In: R.D.Kissinger, (Eds.,), Superalloys, The Mineral, Metals and Materials Society, 705 **(1996)**.

[7] Zainul Huda; Materials and Design, **30**, 3121 **(2009)**.

[8] E.Silveira, G.Atxaga, E.Erauzkin, A.M.Irisarri; Engineering Failure Analysis, **16**, 639 **(2009)**.

[9] E.Nembach, S.Schanzer, W.Schroer, K.Trinckauf; Acta Metall., **35**, 1471 **(1987)**.

[10] Xiu-Bo Liu, Ming Pang, Jian Guo, Gang Yu; Journal of Alloys and Compounds, **461**, 648 **(2008)**.

[11] Xiu-Bo Liu, Ming Pang, Zhen-Guo Zhang, Wei-Jian Ning, Cai-Yun Zheng, Gang Yu; Optics and Lasers in Engineering, **45**, 929 **(2007)**.

[12] Z.Mazur, A.Luna Ramirez, J.A.Juarez Islas, A.Campos Amezcua; Engineering Failure Analysis, **12**, 474 **(2005)**.

[13] Xiaolei Xu, Zhiwei Yu; Engineering Failure Analysis, **14**, 1322 **(2007)**.

[14] Zhi-wei Yu, Xiao-lei Xu, Shu-hua Liu, Yu Li; J.Fail.Anal.And Preven., **7**, 386-392 **(2007)**.

[15] Wei-Ze Wang, Fu-Zhen Xuan, Kuli-Long Zhu, Shan-Tung Tu; Engineering Failure Analysis, **14**, 632 **(2007)**.

[16] E.Poursaeidi, M.Aieneravaie, M.R.Mohammad; Engineering Failure Analysis, **15**, 1111 **(2008)**.

[17] A.Kermanpur, H.Sepehri Amin, S.Ziaei-Rad, N.Nourbakhshnia, M.Mosaddeghfar; Enginnering Failure Analysis, **15**, 1052 **(2008)**.