Pak. J. Engg. & Appl. Sci. Vol. 9, Jul., 2011 (*p.* 98-102)

Cracking Failure in GAS-Turbine Blades

Liaqat Ali, Khalid M Ghauri, and Faizul Hasan*

University of Engineering & Technology, Lahore
Email: liaqat_kasuri@hotmail.com

Abstract

The present paper describes the findings of a failure investigation on the basis of metallographic examination of Gas-Turbine blades of a 3MW power plant in the province of Punjab, Pakistan. Two blades were randomly picked up for inspection from a lot of 61 blades that had been removed from the turbine after annual inspection. The blades were removed on the recommendations of the inspectors (from the manufacturers of turbine) according to which the blades had suffered from corrosion-fatigue cracking at the inlet of the cooling air passage. The objective of the present examination was to establish whether there were any cracks at the inlet of the cooling air passage, and in case any cracks were present, what was the possible cause of such cracking. The investigation showed that cracking at the air-inlet was not due to corrosion-fatigue, but instead the cracks were a manufacturing defect that could be described as 'solidification shrinkage' cracks.

Key Words: Metallographic Examination, Corrosion Fatigue Cracks, Cooling Air Passage, Solidification-Shrinkage.

1. Introduction

Different failure modes in turbine blades, made from super alloys, may be observed in gas turbines. Long-term gas turbine operation leads to the microstructural degradation of super alloy blades. In a number of cases, the structural degradation results in a significant change in the mechanical properties, which can lead to blade failures [1-3]. Thermal fatigue cracks are the characteristic type of edge failures in air-cooled gas turbine blades including those manufactured from single-crystal and directionally-solidified alloys. In long term operation, such cracks also form on blades made from wrought high-temperature alloys [4]. Coating cracking is induced by a local corrosion failure of blade base metal under the coating.

On the other hand, the industrial production of blades by different manufacturers sometimes causes a displacement of the mass centre leading to static failure of blades. Such blade failures have been observed in air craft, marine and stationary gas turbine plants [5]. Another cause of static failure of blades is over- heating caused by a departure from normal operating conditions. The elevated metal temperature results in a drastic deterioration of mechanical properties and above all, in reduced metal fatigue resistance that causes cracking [6].

High-temperature sulfide-oxide corrosion and high-temperature surface de-alloying has also been reported by number of authors [7-10], according to which a decrease in chromium content in a layer upto 100 μm thick was observed. The analyses reported by these authors have revealed a local increase in sulfur content related to sulfide-oxide corrosion attack.

The cracking in turbine blades under investigation was reported by the maintenance team of the manufacturers after the annual inspection of the turbines. It was stated that corrosion fatigue cracks have been observed at the inlet of air-cooling holes, and as a result 61 blades were replaced.

The purpose of the present investigation was to verify whether or not any cracking had actually occurred, and also that whether these cracks, if confirmed, were related to corrosion fatigue or some other phenomenon. The entire basis for conducting this exercise had arisen from the view that the region at which the cracks were stated to have been observed was not subjected to any applied stresses, although, thermal stresses could not be ruled out. Since the location of the cracks had been clearly identified by the inspectors, it was decided to conduct a microscopic study of randomly picked up blades from out of the replaced set.

2. Experimental

The relevant segments of the blades designated as Blade No. 1 and Blade No. 2 were prepared for metallographic examination on the face that was reported to have developed cracks at the edges of cooling air inlet holes. The metallographically prepared section was examined with optical and scanning electron microscope. The morphology of cracks in the base metal as well as in the coating was studied in both samples.

3. Results

The two blades which were examined and the findings are presented in this paper, were randomly picked up from the entire set of 61 blades which had been replaced after the annual inspection. Both the examined blades had cracks at similar locations, i.e., at the inlet of the cooling-air hole. For the purpose of reference, the blades were marked as Blade # 1, and Blade # 2.

Photograph of the turbine Blades are given in Figure1. As may be noted in this photograph, a reddish-brown ‘oxide’ layer was present on the surface of the blades. Nevertheless no deposition of any foreign material was observed.

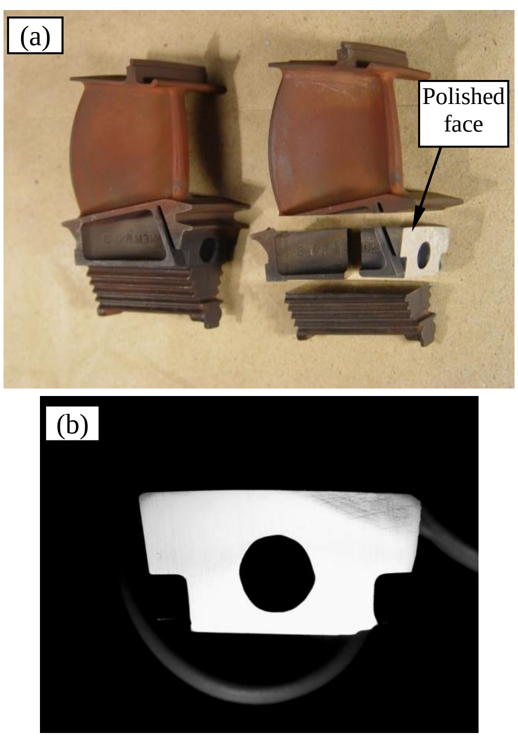

Figure 1: (a & b): Photograph illustrating the manner in which the Turbine Blades were sectioned for metallographic examination.

For metallographic examination, the blades were sectioned in a manner as illustrated from Figure1. The surface which was polished for metallographic examination is indicated by arrowhead. A photograph taken from semi-polished surface of Blade # 1 (Figure 2) shows a crack that could be easily seen with a low power magnifier. It may be pointed out that the crack seen in Figure 2b, was the only crack observed in Blade # 1.

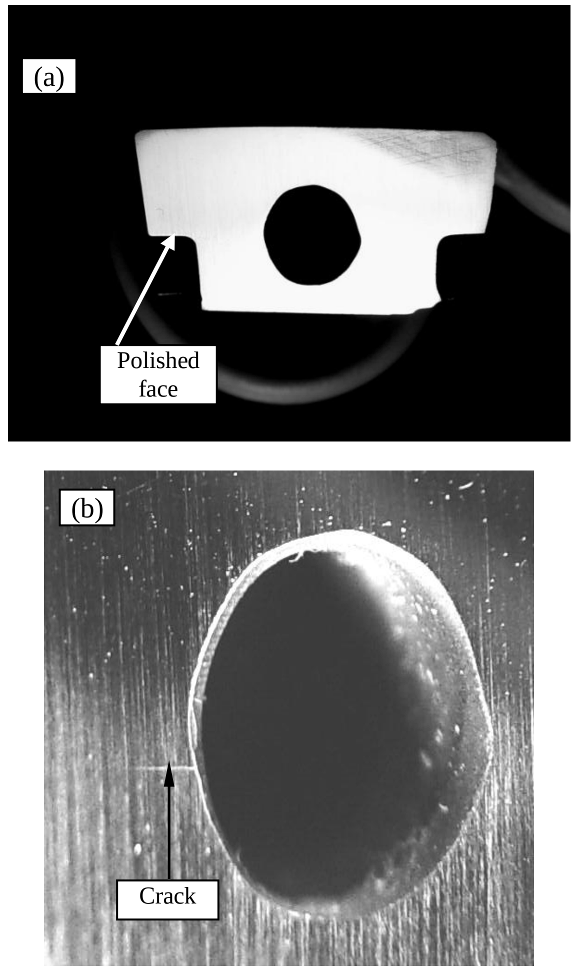

Figure 2: (a & b): Photograph showing the location and orientation of cracks in Blade # 1. The crack became visible to naked eye even before the final stage of polishing.

A Scanning-Electron-Micrograph, given in Figure3b, was taken by tilting the specimen in such a manner that both the metallographically-polished surface as well as a part of the inside surface of the air-inlet hole could be seen. The scanned portion of the two surfaces which were essentially at right angle to each other are schematically illustrated in Figure 3a.

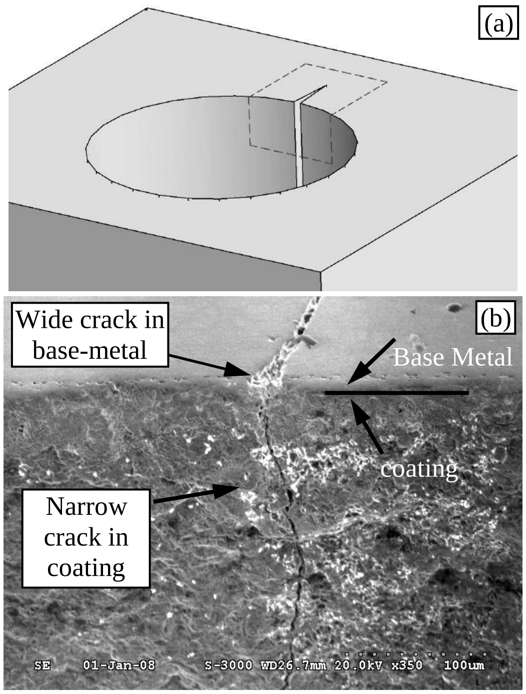

Figure 3: Scanning-Electron-Micrograph taken by tilting the specimen in such a manner that both the metallographically-polished surface as well as a part of the inside surface of the air-inlet hole could be seen. The scanned portion of the two surfaces which were essentially at right angle to each other are schematically illustrated in Figure 3a.

In Blade # 2, four (4) small cracks, in close proximity to each other were observed in the same region of the air-inlet hole as in Blade # 1. Micrographs showing the individual cracks, along with the Scanning-Electron-Micrographs showing relevant details are given in Figures 4-6.

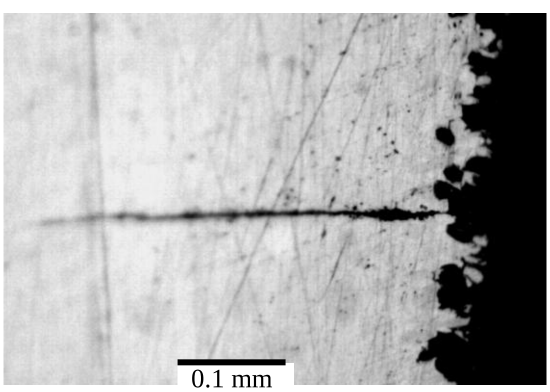

Figure 4: Optical Micrograph showing one of the four cracks in Blade # 2. The narrowness of the crack as it approaches the surface suggests that the crack had essentially formed beneath the surface.

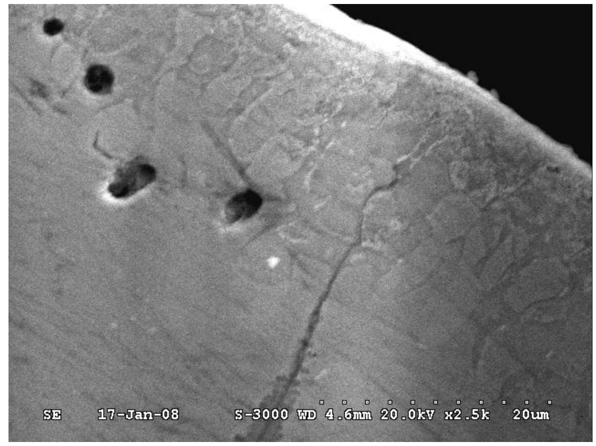

Figure 5: Scanning Electron Micrograph of the same crack shown in Figure 4. It is interesting to note in this micrograph that the coating does not exhibit any cracking at this stage.

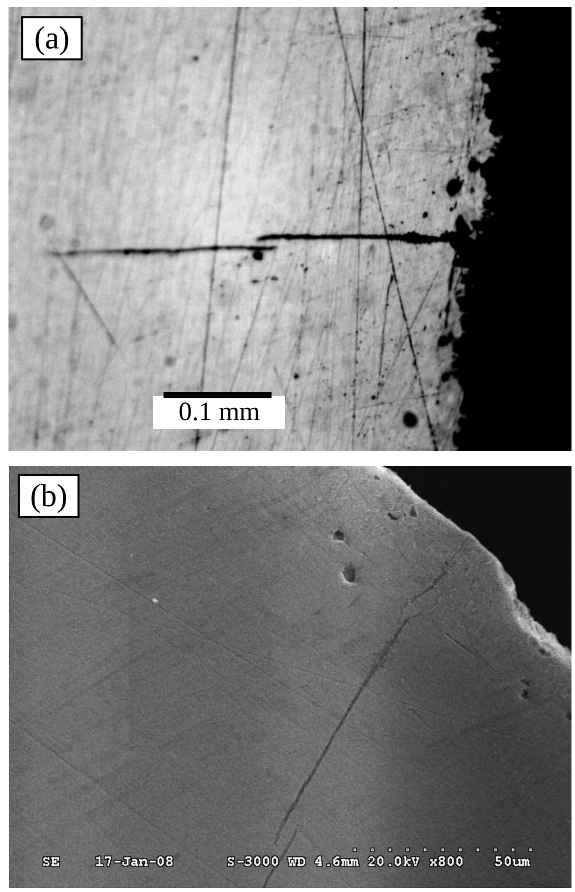

Figure 6: (a & b): Optical and Scanning Electron Micrographs taken from another location of Blade # 2, illustrating that the cracks are not exposed to surface, and hence cannot be related to corrosion fatigue. It may also be noted that in addition to the small crack just beneath the surface, there are two more independent sub-surface cracks.

4. Discussion

4.1 Crack in Blade # 1

As stated above in the Abstract as well as in Introduction sections, as many as 61 blades from a particular stage of the turbine were replaced on the recommendations of the inspectors from the manufacturers of turbine. These blades were stated to have suffered from corrosion-fatigue cracking at the inlet of cooling air passage. In this context, it must be realized that the only stresses that could exist at the inlet of cooling air hole would be thermal stresses caused by incoming cooling-air, as this location was not subjected to any mechanical stress. Hence, whether the cracking was caused by corrosion fatigue or thermal fatigue, it is logical to believe that the magnitude of the thermal stresses would be highest at the inside surface near the entrance of the air inlet hole.

Scanning Electron Micrograph shown in Figure 3 (b) shows the crack An important features associated with the morphology of the crack in Blade # 1 is that the crack in the base metal is much wider than the crack in the coating (Figure 3b). It is very important to note that the crack exhibits its greatest width immediately beneath the coating.

This observation strongly indicates that crack did not initiate at the surface of the air-inlet hole, because if the crack was initiated by thermal stresses caused by cooling-air, it would be of a greater width at its starting point i.e., in the coating. Instead it is more logical to believe that the crack was present in the base metal before the coating was applied, and that the crack had grown into coating either during service or during the cutting and grinding of the blade for metallographic polishing. On the other hand, it can also be argued that these blades were refurbished, and that the coating was applied on blades that already had small cracks at the inlet of air-holes.

4.2 Crack in Blade # 2

The morphology of cracks observed in Blade # 2 provided support to the view that the cracks had actually formed in the base metal, at some stage (possibly before the coating was done), and then these cracks had extended into the coating from inside, either during service or during metallographic cutting and preparation. The occurrence of crack beneath the coating is evident in Figure 4, the crack becoming thinner as it approaches towards the surface and ultimately discontinues before reaching the coating.

A very convincing evidence that the cracks had formed inside the base metal, can be seen in Figure 5, where the crack is not connected to the outside surface, and also that the coating is still intact. This evidence again suggests that the crack had essentially formed beneath the surface, and therefore cannot be related to corrosion and hence not with corrosion fatigue.

Micrographs in Figure 6 (a & b) clearly illustrate that the pattern of cracking cannot be attributed to corrosion fatigue in which the crack has to originate at the surface (i.e., where a corroding agent is available) and then gradually extends into the interior under the influence of stress. Instead, the formation of more than one crack parallel to each other (normal to the direction of ‘tensile’ stress) is more consistent with cracking caused by solidification shrinkage.

4.3 Origin of Cracks

Apart from the morphology of the cracks as discussed above, the location where the cracks have formed is a very important point that provides a lead to the origin of the cracking. In this regard two factors must be kept in view:

- The location of the cracks is not in such a region where alternating stresses of some sizable magnitude could be expected such that any corrosion-fatigue could have been caused. A corrosion-fatigue crack shall need an alternating stress of a sizable magnitude, and shall essentially take a start at the surface, i.e., where a corroding agent is available.
- During the casting of the blade, the air-holes are produced with the help of a ‘core’. This core, because of its intricate and delicate shape, has to be sufficiently strong so that it does not break-off during handling or under the influence of flowing metal during pouring. However, it is quite common that when the core is rigid and ‘non-collapsible’, it may not allow sufficient shrinkage allowance to the solidifying metal, with the result that tensile stresses of sufficient magnitude may develop during solidification to cause the formation of sub-surface cracks in the last-to-solidify region of casting.

The cracks seen in Figures 4-6 are of a morphology typical of subsurface solidification cracking caused by rigid cores. It may be noted in Figs. 5 and 6(b) that the crack is not even exposed to the surface. Further, it may be noted in Figure 6 that in addition to the small crack just beneath the surface, there are two more independent sub-surface cracks which are parallel but not connected to each other.

This pattern of cracking cannot logically be attributed to either thermal-fatigue or corrosion-fatigue. In case of corrosion fatigue, the crack has to originate at the surface (i.e., where a corroding agent is available) and then gradually extend into the interior under the influence of stress. Further, the cracking pattern cannot be attributed even to thermal fatigue, in which case the crack must again initiate at the surface where the maximal thermal stress caused by cooling air may be available. On the other hand, the formation of more than one sub-surface cracks parallel to each other (i.e., normal to the direction of 'tensile' stress), is more consistent with cracking associated with internal solidification shrinkage caused by rigid core.

5 Conclusions

It is evidenced from the metallographic investigations that the cracking in the two randomly picked turbine blades could not be attributed to thermal-fatigue or corrosion-fatigue. There was clear evidence that the cracks were present in the blades before the coating was applied. Regarding the origin of cracks, it is more logical to believe that the cracking was associated with the stresses arising from solidification shrinkage that had resulted from the low collapsibility of core used in the casting of blades. The formation of more than one sub-surface cracks parallel to each other and normal to the direction of 'tensile' stress, is typical of cracking caused by rigid cores at/below the inside surface of the holes.

References

[1] A. V. Prokopenko and V. N. Torgov; Strenght of Materials, 12(4),(1980) pp. 520-523.

[2] L. B. Getsov aand A. I. Rybnikov;Material Science, 28(5),1992,pp.455-458.

[3] A. I. Rybnikov and L.b.Getsov;sixth International Congress on Thermal Stresses, Vienna,Austria,(2005), V.1,pp 305-309.

[4] H. Lee Craig, T. W. Crooker, David W. Hoeppner, Corrosion-Fatigue Technology: a symposium (1978) copyright by American Society for Testing and Materials.

[5] V.T. Troshcenko and A.V. Prokopenko; Engineering Failure Analysis,7(3),(2000), pp. 209-220.

[6] G. T. Nazarenko and I. I. Ishchenko; International Applied Mechanics; 14(9), pp.943-949.

[7] T. W. Crooker , B.N.Leis; Corrosion Fatigue: Mechanics, Metallurgy, Electrochemistry and Engineering (1983), P197.

[8] www.answers.com/topic/corrosion-fatigue-limit

[9] P. M. Singh, J. J. Perdomo, J. E. Oteng and J. Mahmood ; Corrosion, 60(9),(2004).

[10] I. Cerny & V. Linhart; Surface Treatment IV (25), (1999).