INVESTIGATION OF A SHOT PEENED TURBINE BLADE AFTER LONG-TERM USE

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ABSTRACT

The main application of shot peening technology is the increase of fatigue strength by generating residual compressive stress. We wondered about the long-term durability of this effect under operating environments. So the shot peened turbine blade which was used for long term was investigated. The surface and cross-sectional micro structure were examined by scanning electron microscopy. Also the surface roughness and the depth profiles of peened area were measured. The peening marks were found on the surface. The deformed micro structure appeared as curved lath-martensite near the surface of the cross section. Lastly, the hardening layer due to shot peeing was an about 70 ㎛ thick.

KEY WORDS

Turbine blade, long-term use, power plant

INTRODUCTION

The shot peening technology is applied by various industries for long time. The main beneficial effect of this technology is the formation of residual compressive stress on the surface [1, 2]. The residual compressive stress state is especially beneficial to the fatigue characteristics of many mechanical components. Also parts which are sensitive to stress corrosion cracking or welded parts which are susceptible to damage by residual tensile stress can effectively be improved by introducing shot peening compressive residual stresses.

The investigated steam turbine blade of X12CrNiMoV12.2 was rotated at 1,800 rpm in nuclear power plant by the high-temperature and high-pressure steam. In service, the turbine blade is loaded by centrifugal force in radial direction. So the turbine blade was fastened by a dove tail-shaped root to the rotor disc (Fig. 1). This contact area is subjected to severe cyclic stresses, especially during start and stop operation. This operation environment is predominated by fatigue loading. In this study, we investigated the root of a blade which was shot peened in the area of the dove tail. The manufacturer performed the shot peening in order to increase the fatigue resistance by introducing compressive residual stress. The effect of compressive residual surface stresses were estimated by the many mechanical tests and studied by many researchers in lab scale in relatively short-term experiments [2, 3]. Long-term test results are almost unavailable. We tried to examine the long-term durability of shot peening effects under operational environments. The peening-treated turbine blade which was used for long terms was investigated. This blade was used as the first moving blade part of low pressure turbine in nuclear power plant during more than 20 years.

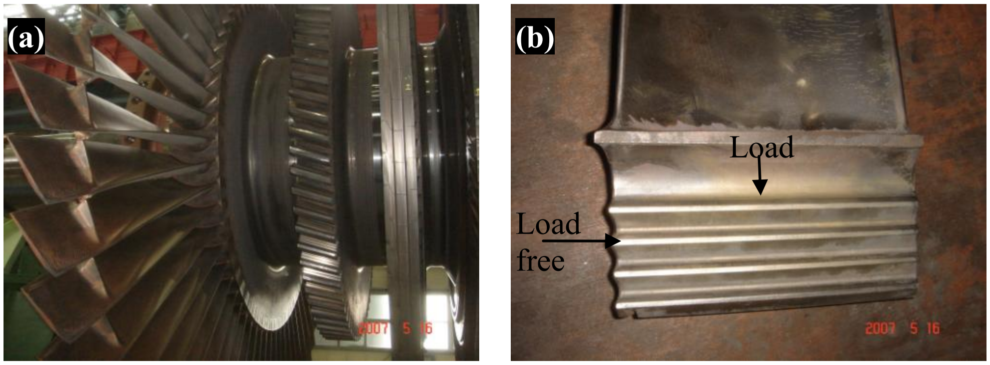

Fig. 1 Photographs of the investigated blade :
(a) turbine rotor (b) dove tail of shot peened blade

METHODS

The long-term used turbine blade was first visually inspected with regard to surface cracks and scratches. The shot peened dove tail part was cut into small pieces for metallurgical investigations. These specimens were cleaned with acetone and ethyl alcohol in an ultrasonic cleaner. The surface roughness was measured by stylus in two directions. The surface and cross sectional microstructure were investigated with scanning electron microscopy. Finally, the depth profile of hardness was measured by nano-indentation equipment.

RESULTS

Surface microstructure

The shot peening was done on the dove tail part of the steam turbine blades for increasing the fatigue strength. The peening-treated part of a dove tail was divided into the two areas. One is the load-free area near the tips of the dove tail profile. The other is the loaded area on the flanks which is in contact with the corresponding dove tail profile of the disc. Fig. 2 shows the surface morphology of the two areas which are described as loaded area and load-free area. The peening marks were evidently existed on the surface of the load-free area (Fig. 2 (a)). The morphology of marks was irregular due to the use of an irregular shot when it was shot peened. This means that the initial working state was maintained. On the other hand, the peening marks on the surface of the loaded area were hardly detectable as shown in Fig. 2. (b). This is due to the interactions with supporting body like wear and sliding with the supporting body during the operation. Fig. 3 shows the measured surface roughness results. The value of roughness in x direction was Ra=4.17 μm and Rz=27.15 μm, and in y direction was Ra=3.65 μm and Rz=11.61 μm.

Fig. 4 shows a magnified peening mark on the loaded area. The center of the mark still shows a crater-like topography whereas the circumference is flattened by plastic deformation during operation in contact with the disc. The small holes (Fig. 4. (b)) were only formed in the circumference area. This is due to the tensile stress state at the circumference unlike the compressive stress state at the center. The surface which is imposed to tensile stresses is susceptible to environmental and mechanical attack such as corrosion and abrasion.

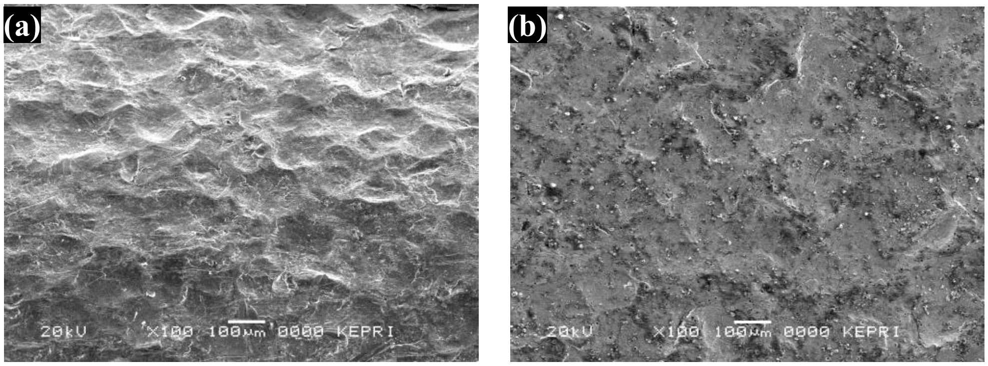

Fig. 2. Surface morphologies of the peened dovetail part ;
(a) load free area, (b) loaded area

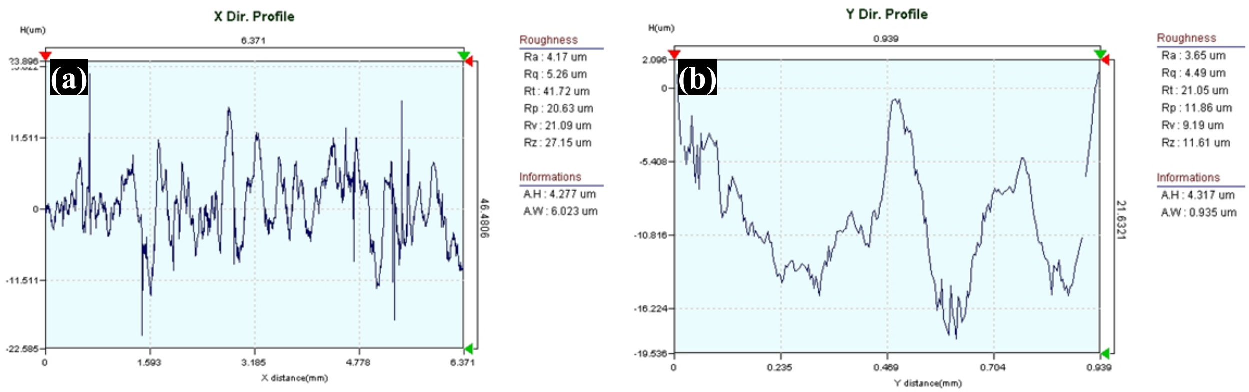

Fig. 3. Surface roughness of the load-free area

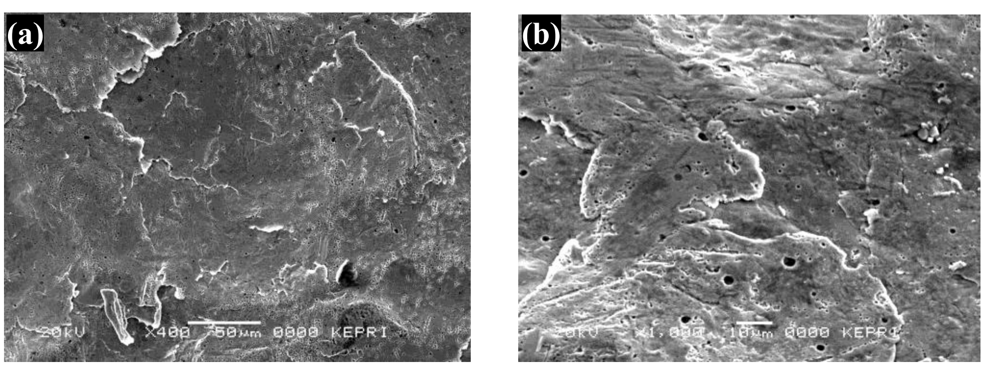

Fig. 4. Surface micro structure of peening marks ;
(a) center area, (b) circumference area

Cross sectional microstructure

Fig. 5 shows the cross sectional microstructure of peened dove tail part. The base metal has a lath-martensite microstructure with straight grain boundaries (Fig. 5. (a)). This is a typical micro structure of the original material. Fig. 5. (b) shows the cross sectional microstructure of the near surface in the load-free area. Unlike base metal, the grain boundaries are curved and disappear near the surface. The laths of martensite appeared in a distribution and shape like as the original state. The dark area in the figure seemed to be a nano-scale strain structure which should be investigated in more detail by transmission electron microscopy. These micro structure changes at the near surface of the shot peened area are interpreted as a result of the plastic deformation by shot peening. Fig. 5. (c) shows the micro structure at the near surface of the loaded area. The evidently deformed micro structure as in the load-free area could not be detected. But it was different from that of base metal. In the loaded area, the visible grain boundaries extended to the free surface. Only small remaining areas of dark nano-scal micro structure and of deformed martensite laths remained. This is expected to be a result of removal of the deformed layers by sliding and abrasive wear. The investigator confirmed, however, that the original deformed micro structure was stable during more than 20 years of operation in the load-free areas.

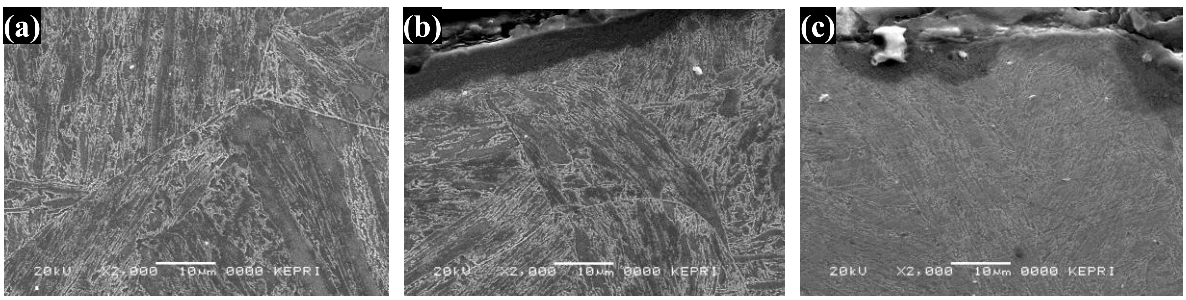

Fig. 5. Cross-sectional microstructure of dove tail ;
(a) base metal, (b) load free area and (c) loaded area

Fig. 6 shows the hardness depth profiles of the loaded and load free area. In lath areas, the thickness of the work-hardened layer appeared to be about 70 ㎛. The hardness level of the load-free area was slightly higher than that of the loaded area.

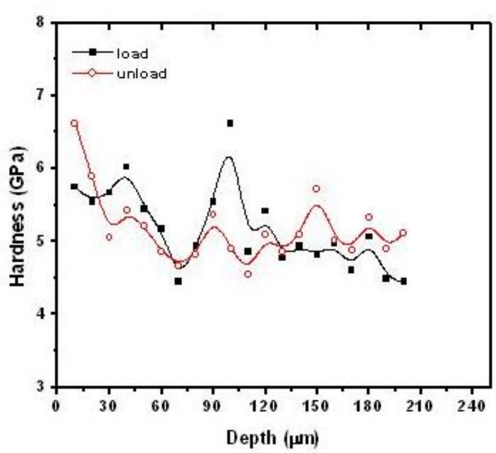

Fig. 6. Hardness of loaded and load-free area with depth

CONCLUSION

The shot peening marks still existed on the load-fress surface even after more than 20 years in operation. The shot peened surface layer still showed the deformed micro structure with curved grain boundaries and martensite laths. Also the work hardening layer was maintained to 70 μm depth from the free surface. In case of the loaded area, the peening marks and the deformed micro structure was partly removed, probably by corrosion-assisted abrasive. The hardening layer was extended to the same depth as in the load-free area.

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