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Roller Pressing or Shot Peening of Fir-Tree Root of LPT Blades of 500 MW Steam Turbine

Mahesh C. Sharma
Maulana Azad College of Technology, Bhopal, India

1 Abstract

An experimental investigation was carried out to explore the possibility of replacing pressure rolling of Fir-tree root of L.P. Blades by shot peening. For this purpose it was necessary to find out shot peening parameters which could achieve the required depth of compression and residual stress as pressure rolling does. Depth is especially crucial when very poor water condition come into effect. Further more surface roughness is a concern for bearing lands. It was necessary to achieve residual stress not lower than -300 MPa down to a depth of 0.25 mm and roughness value R_Z must not be larger than 22 µm after shot peening. In the present investigation surface roughness and residual stress data obtained with different peening parameters were reported. It was observed that pressure peening with 10 mm convergent divergent nozzle, 1 to 1.2 mm cast steel shots, at 0.32A peening intensity, 3 kg/cm^2 tank pressure 12" stand off, 125 to 150% coverage gave residual stress value -418 MPa at 0.25 mm depth in 12% chrome steel test pieces. The surface roughness too was with in required range (Ra = 2.80 µm). Residual stress on an actual blade profile cut section was also verified. Thus roll pressing can be replaced by shot peening.

2 Introduction

The fir-tree root of LP Blades are fitted into the corresponding groove of the turbine disc. They undergo very small amplitude cyclic movement at the root in close contact and under heavy pressure. The minute relative displacement of contact surfaces subsequently causes the rupture of asperity, which then oxidizes. Severe surface damage may soon appear due to the influence of the applied service stresses of the moving parts. Fatigue micro cracks will develop and propagate leading to eventual part rupture. It was reported that shot peening improved fretting fatigue and fretting fatigue strength increases with increasing roughness [1]

The complete interaction fretting/shot peening may be represented diagramatically as follows [2] (table 1):

Table 1: Interaction fretting/shot peening

Fretting Is Due To	Shot Peening Imparts
Contact pressure	Bearing capacity
Normal stress	Residual stress
Displacement amplitude	Peak elasticity
Debris	Debris absorption
Lack of lubrication	Lubrication agent retention
Micro cracks	Micro crack blockage
Hardness	Favorable microstructure
Friction	Favorable morphology

If the decision is to be made to shot peen a particular turbine blade – type of shot peening parameters are determined. The desired distribution of residual stresses is chosen depending on the steel shot. This distribution is characteristic of the component material upon shot peening. However, not only the material behavior during shot peening of component is important, but it has to be checked in a second step whether the chosen residual stress distribution is compatible with the geometric conditions. Experiments with notched specimens have shown that shot peening of notches has a beneficial effect only if the notch radius to be shot peened is several times larger than diameter of shot used [3,4].

Table 2: Chemical composition and mechanical properties of blade material

C 0.18	S 0.010	P 0.015	Si 0.31	Mn 0.48	Ni 0.38	Cr 13.68
Hardness	260 BHN					
Impack energy	100 Joules					
UTS	880 MPa					

Table 3: Surface finish for the blade

Profile	3.2 μm
Root	2.5 μm
Inlet edge, exit edge and fillet	0.8 μm

3 Experimental Work

An actual turbine blade was cut at the end of fir-tree profile and its root were shot peened by pressure peening system as shown in the figure 1. First the peening parameters were decided by shot peening block samples. About twenty block samples of 2" × 3/4" × 1/4" were cut by lesser cutting to make residual stress free test blocks. These test blocks were peened to achieve different peening intensities using suitable peening parameters. At different peening intensities surface roughness and residual stress distribution in the depth direction was experimentally investigated. The recommended residual stress was –300 N/mm^2 at 0.25 mm depth at the fir-tree root and surface roughness lesser than 22μm.

Residual stress data for shot peened blade root to an intensity 0.35A using 1 mm cast steel shots were as follows:

Table 4: Residual stress data for shot peened blade root

Blade Root Spot - 1		Blade Root Spot - 2	
Depth (mm)	Residual Stress (MPa)	Depth (mm)	Residual Stress (MPa)
0.0	- 786	0.00	- 780
0.05	- 639	0.10	- 539
0.10	- 627	0.17	- 553
0.20	- 463	0.30	- 376
0.25	- 461		
0.32	- 393	0.40	- 319

Above results showed that required residual stress distribution at fir-tree root is possible by shot peening with even 1 mm steel shots. This shot diameter was about one fourth the root radii of the blade. Further investigations were carried out using few sizes of bearing balls and shots.

3.1 Ball peening with 3.1 mm Steel Bearing Balls using pressure peening

In order to induce greater depth of penetration of required magnitude of residual stress value – 300 MPa at 0.5 mm depth or even –500 MPa at 0.5 mm depth. Following peening parameters were used.

Table 5: Peening parameters

Comp. Air supply tank pressure	5 kg/cm^2
Discharge of compressed air	2300 litre/min
Pressure pot pressure	1.5 kg/cm^2
Convergent divergent nozzle of throat dia	8 mm
Orifice diameter	12 mm
Half valve opening for uniform flow of balls peening intensity	0.5A
Stand off	1 ft.
At higher tank pressure of 2 kg/cm^2 peening intensity was enchanced to 0.6A	
Ball peening gave surface roughness valve R_a = 4.4 to 6.1 μm	

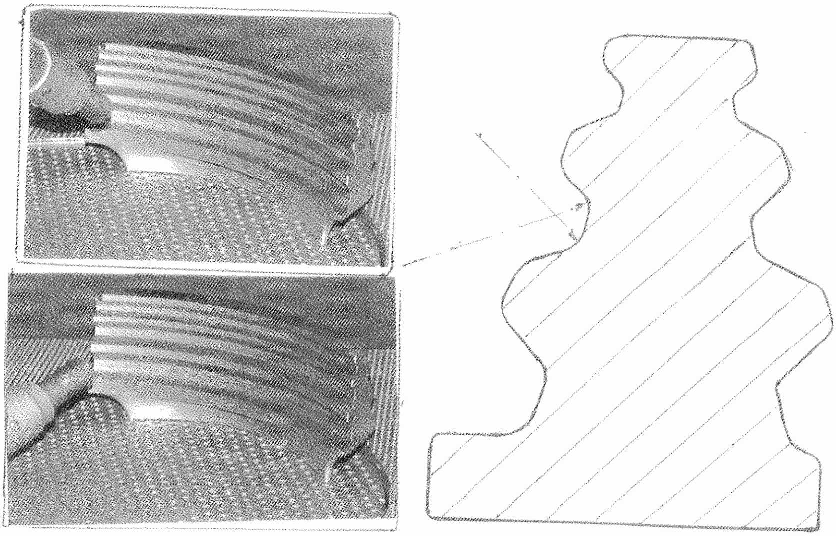


Figure 1: Left : Photographs of turbine blade cut section placed on turn table of pressure peening unit and two positions of nozzles for peening the fir-tree root; right: blade fir-tree root actual profile to full size

Ball peening with slightly higher velocity which could be obtained by increasing tank pressure to 2 kg/cm^2 and an intensity was enchanced from 0.5A to 0.6A. It was found that at a depth of 0.5 mm residual stress was even greater than –500 MPa observation for three different ball peening condition were plotted as shown in figure 2. Figure 2 shows that with intensity 0.5A it was possible to induce –500 MPa up to a depth of 0.4 mm, while with 0.6A at 2 kg/cm^2

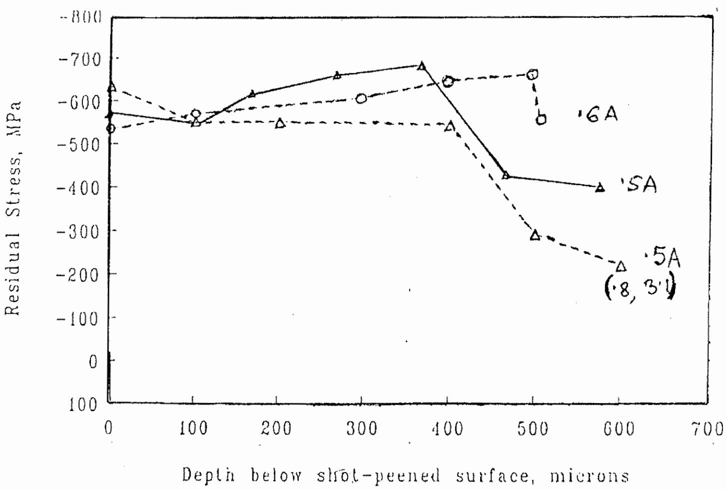


Figure 2: Residual stress distribution by 3.1 mm ball peening using pressure peening

pressure –500 MPa could be induced to a depth of 0.5 mm. Primary peening with smaller shots 0.8 mm and then ball peening was not benefitial as compared to peening at higher intensity with 3.1 mm ball.

3.2 3.1 mm Ball Peening with Syphonic System

Block Samples were ball peened on Syphonic System developed at our end [5].
Following peening parameters were used.

- Bearing Ball 3.1mm dia
- Syphonic Peening System with compressed air supply from a compressor of 15 hp, 1460 rpm and 1850 litres/minute discharge air tank pressure 5 kg /sq. cm., stand off 2" exposure time 3 minutes.

Residual Stress and surface roughness data were as shown in Figure 3

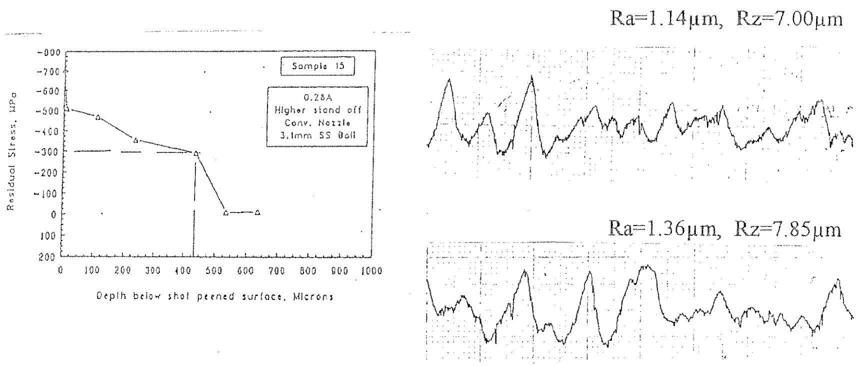


Figure 3: Residual stress distribution by 3.1 mm ball peening using Syphonic peening

With peening intensity 0.28 A it was possible to attain depth of penetration greater than 0.3μm and residual stress at this depth was also greater than –300 MPa. Surface roughness was well within limits R_a = 1.36 μm, R_z = 7.85 μm.

Using same peening parameters but with shot size 4.5mm in place of 3.1mm block samples were peened and residual stress distribution was measured by X-ray diffraction.

The results were plotted as shown in Figure 4. It was observed that depth of penetration was 0.55 μm and magnitude of residual stress was –300MPa at even lower peening intensity of 0.27 A.

Shot Peening with Shot size compatible to Blade root Geometry and its effect on residual stress and surface finish. Block sample were shot peened using shot size: 1.2 mm, stand off: 8 Inch, Air Pressure: 2.0 kgf/sq.cm, Peening Intensity: 0.23 A**,** nozzle: 6 mm throat diameter.

Fig. 5 shows residual stress distribution & surface roughness produced by Shot peening using 1.2 mm steel shots & Pressure peening system.

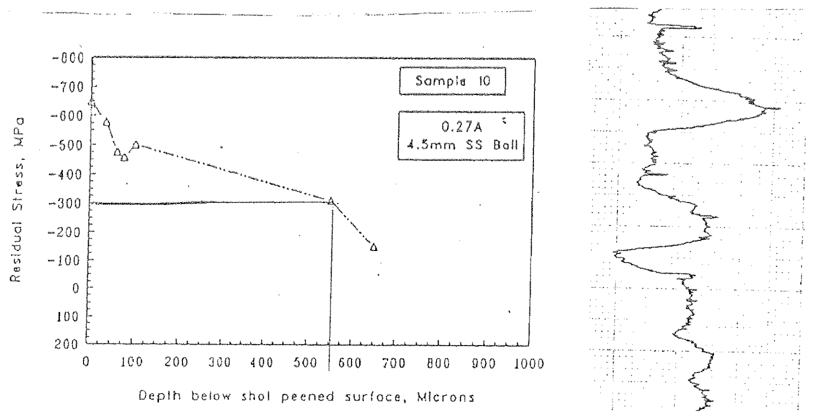
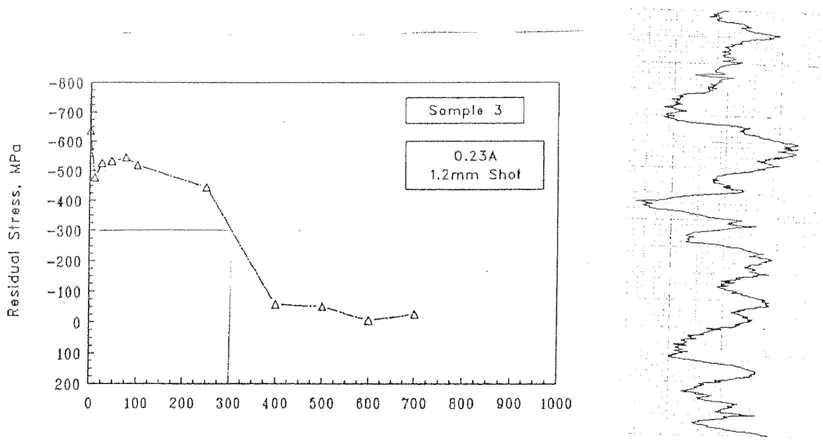


Figure 4: Residual stress distribution and surface roughness produced with 4.5 mm steel bar



Ra = 2.43 µm

Depth Below Shot peened Surface, Microns Rz = 13.12µm

Figure 5: Residual stress distribution and surface roughness produced by 1.2 mm steel shots

4 Results and Discussion

Above experimental results showed that ball peening using 4.5 to 3.1 mm steel ball introduced higher magnitude of residual stress distribution compared to 1 mm steel shots with lower surface roughness. However due to geometric constraints we had to go for smaller shots and it was observed that 1.2 and 1mm steel shots at peening intensities 0.23A and 0.35A respectively could again produced residual stress distribution and surface roughness within limits. Therefore

Shot peening can replace roller pressing of fur-tree roots of LP Blades of 500 MW Steam Turbine. Residual stress results were as follows:

Table 6: Residual stress results

Material Removed After polishing (mm)	Stress MPa	Peening Parameters	% Coverage	Rz
0	–493.9	Shot dia 1.00		
0.050	–482.2	Intensity 0.35 A		
0.100	–461.6	ts = 15 Sec.	150 %	13.82
0.150	–358.6	Pressure Peening		
0.200	–333.2	Peening Pressure		
0.250	–310.6	3 kg/ Sq.cm		

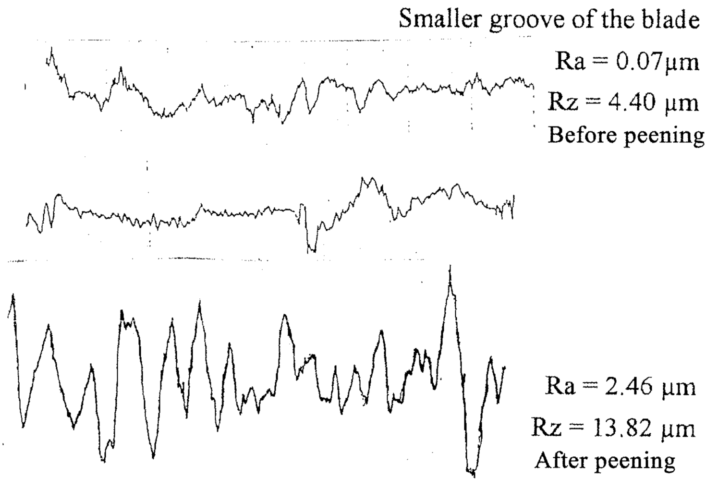


Figure 6: Roughness of blade at smaller and middle groove before peening was R_a = 0.70 μm and R_z 4.40 μm. When block sample was shot peened with 1 mm steel shots to 0.35 A as per above data it was possible to attain –310 MPa residual stress at a depth of 0.250 mm and R_a = 2.46 μm, while R_z = 13.82 (with in limits).

5 Acknowledgements

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6 References

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