EVALUATION OF QUALITY IN SHOT PEENED COMPONENTS WITH BARKHAUSEN NOISE

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ABSTRACT

In this work Barkhausen noise (BN) and X-ray diffraction were used to evaluate samples shot peened to various Almen intensities. Three different kinds of samples were evaluated: (1) a sample (15-5PH) in which shot peening workhardens the surface, (2) a sample (4340M) which worksoftens and (3) a sample (4330M) which is an intermediate case having both work hardening and work softening. The BN response is dependent on the work hardening and softening process. With an increasing shot peening intensity BN is decreased in the presence of work hardening and increased in the presence of work softening.

KEYWORDS

Barkhausen noise, shot peening, work hardening, work softening

INTRODUCTION

In shot peening a shallow surface layer with compressive stresses is generated. The conventional way of measuring these stresses is X-ray diffraction, which is a well-established method and provides accurate stress values. The penetration depth of X-rays is limited to 5-10 μm only, which is too low to properly describe the stress distribution caused by shot peening below the surface. The penetration depth of shot peening is from 0.1 mm to 0.5 mm. To measure the subsurface stresses with X-ray diffraction requires successive removal of material and repeated X-ray measurements. Such a procedure is acceptable for laboratory evaluations on selected samples but is impossible for 100% nondestructive evaluations in shot peened components in the field. Difficult-to-reach areas such as holes, fillets or roots of gears cannot be directly tested with this method. There is a clear need for other techniques which overcome these problems.

Barkhausen noise (BN) analysis method is presently used in several industries including automotive and aerospace to nondestructively inspect surface integrity of camshafts, piston pins, bearings, gears, etc. to insure optimum fatigue performance. BN is well suited for both static and dynamic inspection of the surface. The measurement depth is mainly dependent on the permeability of the material and is typically from 0.1 mm to 0.2 mm for surface hardened components. Since this depth is at least 10 times that obtained by X-ray diffraction, BN has the capability to quantify subsurface stress by inspecting at the surface.

BARKHAUSEN NOISE ANALYSIS

Barkhausen noise is discontinuous changes in the magnetization of material under an applied alternating magnetizing field /1/. The intensity of Barkhausen 'jumps' is known to be dependent on elastic stress, whether it is residual or applied /2,3/. It is also known that BN is sensitive to grain size, dislocations, precipitates, texture and hardness /4,5/.
Stress dependence of BN is shortly the following: High compressive stresses generate low levels of BN. With decreasing compressive stress, the BN intensity is gradually increased. As the stress changes from compression to zero stress and further to tension, the noise increases simultaneously. Based on the above interaction of stress and magnetic field on the noise, the stress level of a ferromagnetic material can be determined by applying a known alternating magnetizing field and measuring the magnetic noise, also called magnetoelastic signal or parameter (MP), created. Some calibration curves obtained in this fashion for three different materials are shown in fig. 1 /6/. It is seen that the level of BN signal will vary from material to material. The effect of residual stress on these calibrations curves is not corrected.

The effect of microstructure can be broadly described in terms of hardness. It is well established that mechanically hard materials are also magnetically hard, i.e., strong applied fields are required to change the magnetic state of a hard material, which means that the BN level will decrease with an increasing hardness in the way shown by the experimental curve of fig. 2 /7/.

A schematic block diagram of a typical Barkhausen noise equipment is shown in fig. 3. A U-shaped magnetizing yoke is used to generate the alternating magnetic field. A sensing coil wound around a ferrite core will detect the BN signal.

**SHOT PEENING**

The main benefit of shot peening is the high compressive surface stress state, which increases the resistance to fatigue failures, corrosion fatigue, stress corrosion, hydrogen assisted cracking, etc. In addition to compressive surface stresses shot peening changes roughness or topology and hardness of the surface by cold working both of which affect the fatigue behaviour of the metal.
In shot peening hardness can increase or decrease depending on the combination of the hardness of the material before shot peening and on the intensity of the shot peening /8,9/. Fig. 4 shows schematically how shot peening intensity affects the work softening/hardening of the surface of a steel with medium hardness. Full width half maximum (FWHM) of the X-ray diffraction peak correlates with hardness so that the harder the material, the higher the FWHM value. In fig. 4 area A has the hardness of the bulk. Area B represents work softening and area C work hardening. At the beginning of the shot peening, the surface first worksoftens. When the surface hardness in area C has been decreased under a certain level, the surface will start work hardening.

The effect of surface hardness before shot peening is shown in fig 5. When the hardness of the steel is low, the surface will mainly workharden in shot peening and when the hardness is high it will mainly worksoften. In the intermediate hardness range the shot peened surface both worksoftens and workhardens. In fig. 5, the microhardness distribution of the shot peened layers is also shown. In general, microhardness measurement of the shot peened surface yields higher hardness values than one would expect based on the values of X-ray diffraction peak width. This can be explained based on the high hydrostatic compression state of the shot peened surface which decreases the indentation size. Therefore microhardness measurements show higher hardness compared to the surface without high compressive stress. Based on work reviewed by Vöhringer /9/ it can be estimated that an increase of 100 MPa in compressive stress state increases microhardness value by about 12 HV0.1 units.

Warren-Averbach diffraction peak profile analysis shows that a change from work hardening to work softening takes place when the hardness of the material exceeds 50 HRc (fig 6). Under the hardness level of
50 HRC the root mean square strain, $\langle e^2 \rangle^{1/2}$, increases in shot peening indicating work hardening. Over 50 HRC it decreases indicating work softening. This observation is in agreement with fig. 5 where the FWHM increases in shot peening for relatively soft normalized condition and decreases for the hard quenched condition.

Work softening is mainly related to the rearrangement of dislocations into a lower energy level in the same way as in fatigue softening. Rising surface temperature caused by shot peening affects in the same direction, helping dislocations to move.

EXPERIMENTAL PROCEDURE

Flat test specimens of 15-5PH precipitation hardening steel and of two different high strength steels (4330M and 4340M) were investigated. The hardness of the steels is given in table 1.

A new commercial equipment µSCAN 500 was used in Barkhausen noise measurement. This equipment is a PC-based system; all measurement parameters are set, commands given, results calculated and displayed through PC. A special feature of µSCAN 500 is the wide analysis frequency range (1 KHz - 2.5 Mhz) of BN.

All BN measurements were taken exactly at the same point as X-ray stress measurements. BN measurement parameters for different steel samples are given in table 1. The BN sensor was a so called AST general purpose sensor.

<table>
<thead>
<tr>
<th>steel</th>
<th>hardness</th>
<th>magn.freq.</th>
<th>magn.volt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-5PH</td>
<td>45.3 HRC</td>
<td>400 Hz</td>
<td>15 V</td>
</tr>
<tr>
<td>4330M</td>
<td>43.0 HRC</td>
<td>100 Hz</td>
<td>7 V</td>
</tr>
<tr>
<td>4340M</td>
<td>57.5 HRC</td>
<td>100 Hz</td>
<td>7 V</td>
</tr>
</tbody>
</table>

Table 1. Barkhausen noise measurement parameters.

X-ray stress measurements were carried out by AST model X2002 X-ray diffraction equipment. For depth measurement of stresses and FWHM the measurement point was electrolytically etched by Struers Movipol-2 pencil type etching head. No correction was done due to material removal.

MEASUREMENT RESULTS AND DISCUSSION

First, the influence of the shot peening intensity on BN was investigated. In fig 7 Barkhausen noise values of the steel samples are shown as a function of Almen intensity. The BN values are presented as percentage changes compared to the lowest shot peening intensity. The BN values of 4330M and 4340M steel samples increase as a function of Almen intensity whereas the BN value of 15-5PH steel sample slightly decreases. Normally it is supposed that BN reading should decrease as a function of shot peening intensity.
because of an increasing compressive stress state. Similarly, increasing cold working is supposed to decrease BN by increasing the hardness of the surface layer.

X-ray diffraction stress results are shown in the upper part of fig 8. The depth of compressive stress layer of all the three steels investigated increases constantly as a function of increasing shot peening intensity. The maximum compressive stress is only slightly affected by the increasing shot peening intensity. The difference in maximum compressive stress between different steels is, however, quite pronounced.

Based on FWHM results given in fig. 8, the surface of 4340M steel worksoftens in shot peening. The 4330M steel also softens, although this softening is less noticeable and takes place in subsurface layers. It is interesting to note that the BN readings of these steels increase with increasing Almen intensity. The surface of 15-5PH steel workhardens as indicated by an increase in FWHM. For this steel, the BN values decreased in shot peening. Based on these results, the BN values will increase in the presence of work softening and decrease in the presence of work hardening.

Whether the cold working process in the present steels is work softening or work hardening seems to depend on the FWHM values of the unpeened surface. The FWHM is clearly highest (5.45°) for the 4340M steel which worksoftens and lowest (2.27°) for the 15-5PH steel which workhardens in shot peening. This dependence appears to be more evident than the dependence of work softening and hardening on the hardness of the unpeened surfaces. Although 4330M and 15-5PH steels have approximately the same hardness (see table 1), 15-5PH steel exhibits strong work hardening, whereas 4330M steel exhibits both work hardening and softening. A probable reason is that the 15-5PH steel is a precipitation hardening steel. The small precipitates create the hardness when at the same time low FWHM values are obtained due to the relatively dislocation free matrix. In shot peening it is mainly the matrix that is deformed. Both BN and X-ray diffraction methods will mainly respond to changes in the matrix.

The depth distributions of FWHM for the present steels correlate with the results of references /8,9/. As the depth of the workhardened and/or worksoftened layer increases, so does the depth of the compressive residual stress layer. At the same time the BN systematically either increases (4340M and 4330M) or decreases (15-5PH). Hence, although the BN is mainly influenced by the work hardening and softening processes, it, through this dependence, also correlates with the depth of the compressive stress layer. Based on the results which show that BN correlates with Almen intensity, it is possible to conclude that BN can be used to evaluate the shot peening process.
CONCLUSIONS

Based on the results of this work, the following main conclusions can be made:

1. The response of Barkhausen noise to shot peening is dependent on the work hardening and work softening caused by the cold working effect of the peening process.
2. In the presence of work hardening (soft steels), Barkhausen noise will decrease with an increasing Almen intensity and in the presence of work softening (hard steels), it will increase.
3. Barkhausen noise correlates with the depth of the compressive residual stress layer.
4. Barkhausen noise is able to measure the shot peening intensity.

Figure 8. Depth distribution of residual stresses and FWHM values of three different steels (4340M, 4330M, 15-5PH) measured by X-ray diffraction.
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