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Shot Peening on Pelton Wheels: Methods of Control and Results

Paolo Marconi
2 Effe Engineering s.u.r.l., Manerba del Garda, Italy
Marco Lauro
Enel Produzione S.p.A., Turin, Italy
Walter Bozzolo
Enel Produzione S.p.A., Turin, Italy

1 Abstract

Shot peening is normally used to increase fatigue resistance in rather small-sized mechanical parts (gears, transmission shafts, connecting rods).

Residual stress induced by this treatment has been studied extensively in the past decade.

Some automobile manufacturers have recently introduced specifications concerning the depth of residual stress in gears.

Most of the research done on this topic has made use of the X-ray diffraction method to determine residual stress.

Because of the configuration of Pelton wheels, shot peened areas cannot be easily accessed with portable diffraction meters. For this reason, the authors have used the Barkhausen noise method to measure residual stress and have then compared results before and after peening. The Barkhausen noise method was calibrated against Almen strips by X-ray diffraction and by hole drilling methods.

2 Shot Peening

The purpose of shot peening is to increase fatigue resistance in mechanical parts. Essentially it is a process in which the surface of the part is bombarded with spherical particles made of the appropriate material and to the correct size. The impact of these spheres on the surface of the part causes a plastic deformation and creates "microcups" which are evident in the following SEM image:

This plastic deformation induces a state of compression which significantly increases resistance to fatigue. Obviously the performance of the part depends on the depth and on the value of compression. These variables (depth and value) are a function of shot peening procedure parameters, which are defined by intensity, shot size and coverage.

Intensity is determined by measuring the effect of peening on an Almen strip, which is a hardened C70 steel strip tempered to 44-45 HRC; strip dimensions are indicated in the following sketch (MIL-S-13165C and UNI 5394-72).

Figure 1: shot peened aluminium surface

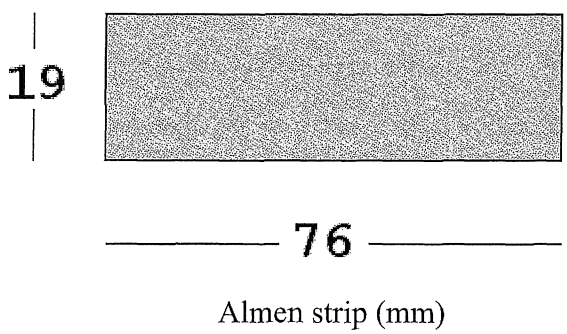

Figure 2: Almen strip (mm)

Deformation, and therefore peening intensity, is expressed in Almen readings which are divided in N, A and C, according to the thickness of the strip.

The size of the shot is chosen on the basis of the desired intensity (the higher the intensity, the bigger the shot) and depending on the geometrical aspects of application (for example, a feeding hose with a small radius).

Coverage is a function of peening time and is measured by visual inspection (30x magnification). The proportion between peened surface and toal surface (expressed as a percentage) gives the coverage value (MIL-S-13165C and UNI 5394-72).

2.1 Measurement of Induced Residual Stress

As previously stated, the increase in resistance to fatigue is due to induced residual stress. However it must be noted that peening parameters are determined on the basis of tests done on Almen strips, which in most cases do not have the same geometric or metallurgical characteristics of the part to be peened.

In order to overcome this problem, some of the more well-known automobile manufacturers have recently established internal procedures which no longer refer to traditional parameters for shot peening of gears (intensity, shot size, coverage), but instead refer to depth and value of induced compression.

The profile of residual stress is usually obtained through X-ray diffraction. Diffraction of X-rays is a non destructive method of measuring residual stress, however only at surface level, since at most the X-rays manage to penetrate about 10 microns beneath the surface. In order to obtain a reading at the desidered depth it's necessary to strip away successive layers of material by electrochemical means; this process does not induce further residual stress [1].

Another method, which however is difficult to apply to automobile gears, is by hole drilling. Through the use of strainmeters (or extensometers), a reading is made of the deformation caused by the release of tension after drilling a small hole in the part. By drilling the hole in stages at deeper and deeper levels, it's possible to measure residual stress in the part.

2.2 Shot Peening Control on Pelton Wheels

Controlling stress induced by shot peening (and therefore controlling the increase of resistance to fatigue as a result of peening) on Pelton hydraulic wheels is problematic. In fact, even though the invasive effects of in-depth X-ray diffraction or hole drilling are negligible on such large parts, the problem is gaining access to the area to be measured, as shown in the following photograph:

This problem became evident during peening qualification procedures by ENEL Produzione. On that occasion a cooperation agreement was established between 2Effe Engineering and ENEL Produzione in order to determine residual stress both with traditional methods (hole drilling and strainmetering by ENEL Produzione) and with non invasive alternative methods such as X-ray diffraction and Barkhausen noise measurements done by 2Effe Engineering.

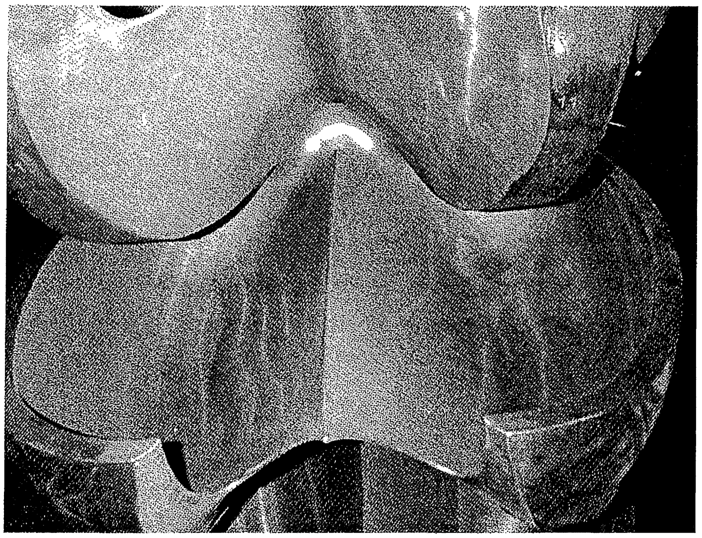

Figure 3:

2.3 Barkhausen Noise Method

The Barkhausen noise method can be applied only on ferromagnetic material (iron, cobalt, nikkel and their alloys). As is well known, magnetic domains in these materials are usually oriented in casual directions and therefore overall magnetization is nil. Application of a magnetic field or a mechanical deformation determines a change in the magnetic domains which in turn determines a change in the overall magnetization of the part. By applying an alternating magnetic field and by measuring the intensity of the movement of the domains through a coil in which this movement produces a periodic electrical noise (Barkhausen noise), it's possible to relate the noise level to the level of mechanical pressure. The intensity of the noise is influenced by various microstructural parameters (shot size, hardness, residual austenite content, etc.) in addition to, of course, by the chemical composition of the part. Generally speaking, it can be said that higher noise levels correspond to residual tensile stress, whereas compression leads to considerably lower noise levels (obviously in the presence of the same material and microstructural conditions) [2]. In order to obtain a calibration curve, which is necessary in order to transform the values of Barkhausen noise into residual stress, shot peening with 2 different intensities (11 and 14 Almen A) was carried out on samples of the same material (steel 13 Cr 4 Ni) and the same thickness. These samples were comparable to those areas of Pelton wheels which are shot peened. Measurements of residual stress were then taken on these samples with the X-ray diffreaction and hole boring methods. The results appear in the following diagram, in which stress levels are measured in 2 directions:

In-depth stress levels measured with the hole boring method are as follows:

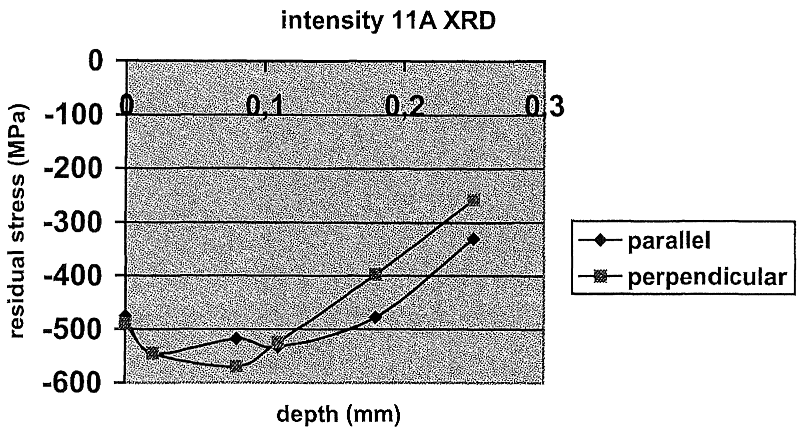

Figure 4:

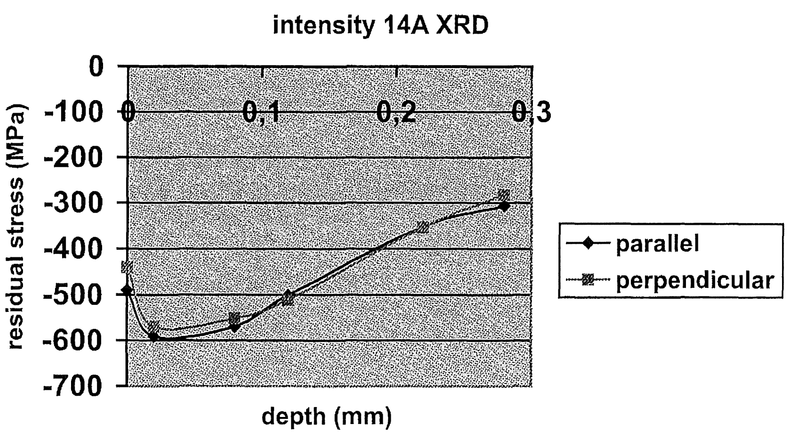

Figure 5:

The following are Barkhausen noise levels measured with a magnetic field at 7-20 KHz frequency, corresponding to a depth of penetration of about 0.2 mm:

Table 1: Barkhausen noise levels

untreated surface	peened 11A	peened 14A
3000	5000	5500

As can be seen, measured values contradict the Barkhausen noise theory. In fact, peened surfaces give a much higher noise level compared to the unpeened surface (when measured with

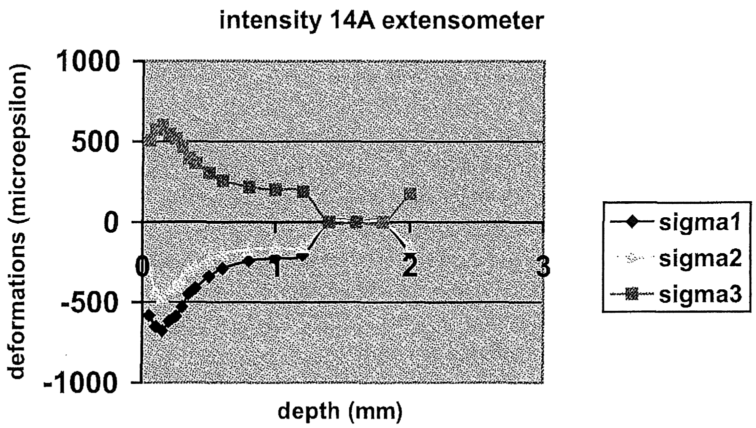

Figure 6:

the X-ray diffraction method, the unpeened area has a surface compression of –67 Mpa in the perpendicular direction and –199 Mpa in the parallel direction).

The explanation for this phenomenon lies in the residual austenite content. This phase of iron (face-centered cubic lattice) is non magnetic, in addition to being unstable at low temperatures [3]. Therefore the presence in the sample piece of this type of iron, because of the heat treatment which it underwent, lowered the Barkhausen noise level. The subsequent peening procedure transformed residual austenite into martensite and this changed the magnetic behaviour of the material and increased the Barkhausen noise level, even though peening created high levels of compression, as was measured by the X-ray diffraction and the hole boring methods. Measurements made on residual austenite by X-ray diffraction have demonstrated the validity of this thesis, showing the following transformation of austenite:

Table 2: Transformation of austenite

untreated surface	Peened surface 11A	Peened surface 14A
Retained austenite (%)	Retained austenite (%)	Retained austenite (%)
10.6	<1	<1

3 Conclusions

The purpose of peening hydraulic Pelton wheels is to increase fatigue resistance. The use of Almen strips does not ensure appropriate residual stress levels which are necessary to achieve the desired increase in fatigue resistance, even if the strips are placed in positions which reproduce the actual areas to be peened. Refined techniques which give reliable results, such as X-ray diffraction and hole boring, are not easy to apply because of the shape of the piece and difficulty in accessing the area involved. The Barkhausen noise method, appropriately calibrated with X-ray diffraction and hole boring methods, does not encounter the same difficulty as the other methods, but gives results which are drastically influenced by the change of magnetic properties induced by peening in the presence of residual austenite. In fact, compression induced by peening tends to lower the noise level, whereas a reduction in austenite content tends to raise the noise level. This problem can be avoided by measuring Barkhausen noise levels before and after shot peening in order to quantify the change. In fact, low starting noise levels, with the same type of surface treatment, indicate a high residual austenite content which will considerably increase noise levels once it changes because of peening. Vice versa, high noise levels implicate low volumes of residual austenite and subsequent peening will considerably reduce these levels. In both cases the difference in noise levels induced by peening is a function of peening intensity. This allows the method to contribute significantly towards evaluation of peening results. Obviously this difference can be fully understood by calibrating with X-ray diffraction o hole boring and by considering the amount of residual austenite.

4 Bibliography

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