Quantitative Characterization of Peening Processes Using X-ray Diffraction Residual Stress Analysis

The residual stresses present in manufactured components, assemblies and structures can significantly improve or diminish their useful life. Proto Mfg. has been helping companies for over 20 years with the measurement of residual stresses in the laboratory, on the shop floor and in the field by providing both sales of standard and custom instrumentation as well as measurement services.

Why Use XRD Analysis?

X-ray diffraction (XRD) based residual stress measurements have been applied to the quantitative characterization and evaluation of numerous peening processes in a wide variety of applications and industries. As such, XRD has been a very flexible and invaluable tool for process development and optimization where the best peening parameters for a given component must be characterized quantitatively. Components treated with conventional peening/blasting media such as cast shot, cut wire and glass bead (as well as those treated with more unconventional treatments such as laser shock peening) have been successfully characterized using XRD techniques. Peening is often used to introduce compressive surface and near surface residual stresses in components and if applied correctly, can provide a significant improvement in component performance and service life. The designed fatigue life and/or warranty period is achieved or exceeded with the aid of peening in many cases where unpeened components may fail prematurely. Since peening is a value added process, its effects should be optimized using XRD analysis to obtain the most “bang for the buck”. Characterization of residual stresses in peened components provides the information engineers and manufacturers need to properly manage the peening process to optimize product quality, minimize the effects of fatigue and stress corrosion for the end user, help minimize development and production costs, potentially reduce component weight and enhance component performance.

How does XRD work?

X-rays are diffracted by atoms arranged periodically in the grain structure of crystalline and polycrystalline materials such as metals and ceramics (see figure 1). The angle of a diffracted x-ray beam \( \theta \) is related to the atomic lattice spacing \( d \) via Bragg's law: \( n \lambda = 2 d \sin \theta \) where \( \lambda \) is the wavelength of the incident x-ray beam and \( n = 1 \) for first order diffraction (see figure 2). By measuring the diffraction angle \( \theta \) for a given wavelength \( \lambda \), the atomic d-spacing and thus the strain can be calculated for the sampled volume. The stress is then calculated by applying elasticity theory.

What can XRD tell that the Almen strip cannot?

Peening effectiveness is normally characterized via the Almen intensity and the % coverage. It should be noted that many potentially different residual stress gradients can result from what may appear to be the same deflection of the Almen strip and observed % coverage. The % coverage is an optical assessment of the “as peened” surface, and is generally thought of as a measure of the uniformity of peening on the component surface. However, uniform coverage does not always result in a uniform stress state. Consider the following example of a weldment shot peened with CW-28 shot at 16-18A in-
X-RAY DIFFRACTION RESIDUAL STRESS

tensity with 125% coverage. To verify
the effectiveness of the peening process,
a section of the weld was masked off
and was not peened so as to compare
the "peened" and "as welded" condi-
tions (see figure 3). The residual stress
was mapped over an area encompass-
ing both the peened and unpeened
portions of the weld and parent mate-
rial. It can be seen in figure 4 that the
shot peening technique used had a
significant effect on the stress state of
the weld and parent material as seen
by the "step" or drop in residual stress
near the center of the map. On the left
hand side of the map the "as welded"
stress state has tensile residual stresses
in the weld and the weld heat affected
zone (HAZ) and neutral or slightly
compressive stresses on average in the
parent material. The right hand side of
this map shows the peened area where
the characteristic profile is much more
compressive (less tensile) and uniform
in the parent material but a reduced
tensile residual stress state remains in
the weld. This indicates that the peening
process had the effect of reducing the
tensile residual stresses in the weld and
HAZ while introducing compressive
residual stresses in the parent mate-
rial. The peening was not sufficient to
force the weld and HAZ entirely into
compression in the sampled volume.
This would suggest that the peening
parameters could be changed to in-
crease the compressive residual stress
imparted upon the weld and HAZ or
that a stress relief heat treat cycle could
be applied prior to peening. This kind
of information cannot be obtained using
the standard Almen strip test and the
assessment of the % coverage.

Can one use XRD in the lab?

Yes. XRD has been used extensively
to measure the residual stress in peened
components in a laboratory environ-
ment. Since varying peening param-
eters can result in different subsurface
residual stress gradients, the residual
stress in peened components must
initially be evaluated as a function of
depth. Figure 5 shows a lab based
XRD instrument characterizing residual
stresses in titanium alloy components.
The stress vs. depth profiles for various
peening parameters on the titanium al-
loy components can be seen in figure
6. In this case, the effect of varying the
peening intensity on the same compo-
nent resulted in quite different residual
stress gradients as a function of depth.
This information was used to select
the best peening parameters for the
intended application.

Can one use XRD inline and in audit
stations?

Yes. Recent advances in detector
technology and computing power
have made XRD based residual stress
measurement data acquisition and
analysis possible in near real time.
Once the residual stress profile as a
function of depth has been established
for a given component and process, sur-
face measurements can be performed
completely nondestructively for 100%
inline inspection and quality assurance.
Since XRD can be used to measure sur-
face residual stresses nondestructively
it can be used to: a) track changes in
the residual stress on the exact same part
at the exact same location through vari-
ous production stages, b) quantitatively
monitor the resultant residual stresses

Can one use XRD in the field?

Yes. XRD has been used on large com-
ponents on the shop floor and in the
field. Residual stress measurements
were performed on a large pinion gear
at different locations where various shot
peening parameters were applied (see
figures 7 and 8). The resultant residual
stress vs. depth plot (see figure 9) dem-


Fig. 4: Stress map on weldment

Fig. 5: Measuring residual stress on a shot
peened component in the lab

Fig. 6: Comparison of various peening
parameter for a component in the lab

Fig. 7: Measuring residual stress
on a component in the field
and c) subsequently provide verification of quality. Thus, XRD can be used to determine when and how potentially harmful stresses are introduced into a component. The effectiveness of potential corrective actions can then be evaluated, implemented and monitored.

How can one apply XRD to their parts?

XRD has been used to help identify stress fields created by overpeening that may actually decrease the service life of a component. It has also been used to help narrow the scope (i.e. the number of parts) for fatigue testing which can be quite expensive and time consuming. XRD can be used as a quality assurance tool in audit stations or for 100% inline inspection. XRD can also be used in the laboratory or in the field for process optimization.

Every application, every problem... Proto has a system that meets your needs.
X-RAY DIFFRACTION RESIDUAL STRESS MEASUREMENT AND SHOT PEENING

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