PEENSTRESS SOFTWARE SELECTS SHOT PEENING PARAMETERS

Yves LE GUERNIC, MIC France
John S. Eckersley, Metal Improvement Company, Detroit, MI

ABSTRACT

Peenstress is a software able to predict residual stress profiles induced by shot peening on most metallic materials. This presentation will show you how *Peenstress* works and will be illustrated by three typical case histories.

KEY WORDS

Shot peening - Residual stress profiles - Optimization - Experimental readings

INTRODUCTION

Optimization of the effects of shot peening is achieved by a careful selection of the basic parameters. These include composition, hardness and size of the peening media, the transferred energy at impact (which controls the depth of the compressive layer), and the percentage of coverage. The many possible combinations of these factors make the correct choice a difficult one, one that is often inadequate. Given the potential for premature failure, it is of the utmost importance that the first selection should be correct.

It is for this reason that Metal Improvement Company, Inc. in collaboration with ENSAM, a French advanced engineering school, have developed *Peenstress*, a computer program that is capable of predicting the residual stresses that are introduced by controlled shot peening in most of the engineering metals: mild and high strength steels, stainless steels, carburized and carbunitrided steels, aluminum alloys, titanium alloys and the nickel alloys. MIC has been using *Peenstress* for over two years and we have collected a significant number of case histories on actual applications.

USING THE NEW *PEENSTRESS* PROGRAM

1. The first step is to select the part material from the metals and alloys in the *Peenstress* library. Over 50 metals are currently recorded in the program library and more are added from time to time, as needs arise.

2. Next, we select the shot composition and size, as well as the Almen intensity which experience would be appropriate for the application.

3. *Peenstress* will calculate the shot velocity that is required to produce the selected Almen arc height or intensity.

4. *Peenstress* will use this shot velocity in all subsequent calculations.

5. The first calculation is the determination of the elastic deformation caused during the actual peening on a "massive body" (theoretically infinitely thick) of the selected peening parameters. This is a complex calculation but the *Peenstress* program does it for us.

6. *Peenstress* then uses material behavior laws for steady and cyclic loading to determine the elasto-plastic deformations on the massive body and the corresponding residual stress in both magnitude and depth.

7. Finally, *Peenstress* allows us to select a geometry related to that of the structure or component to be peened and determine what the residual stress will be in that structure after peening. The selection of geometries include a massive (thick) part, in a thin plate, a hole, a round bar, etc., with these being shot peened on one side only, on opposite sides, all over... with the same intensity on both sides or even with higher intensity on one side than the other.

Material Library

Material:	Aluminum 7010 T 76

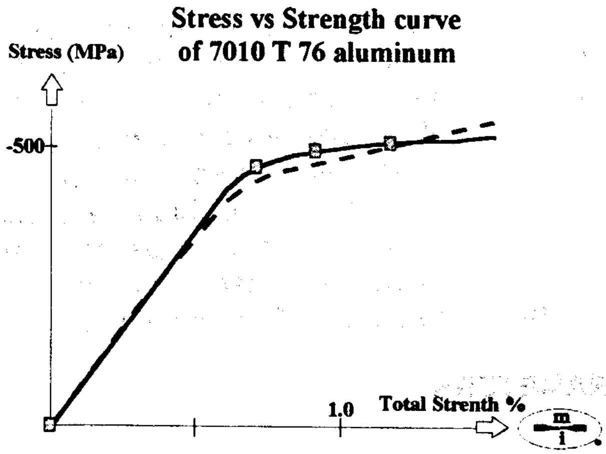
Elastic Limit (MPa):	472
UTS (MPa):	560
Elongation (%):	10
Young Modulus (MPa):	71000
Poisson's Ratio:	.3

	Monotonic	Cyclic
k factor (MPa):	607.60	641.20
n factor:	.0272	.0446

Remarks: ENSAM/Prof. Ericson/20 cy.

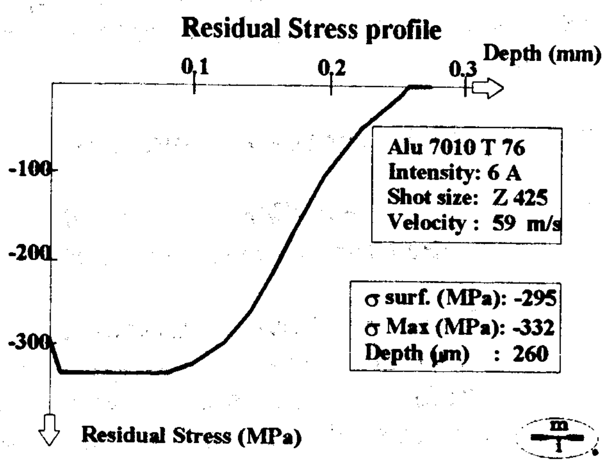
Fig. 1a Materials Library

The selected material is aluminum alloy 7010 T 76. Screen printout shows the monotonic strength coefficient *k* and the strain hardening exponent *n*, as well as the cyclic strength coefficient *k'* and the strain hardening exponent *n'*, which define the true monotonic stress strain curve and the cyclic stress strain curve, respectively. Also shown are the ultimate and yield strengths, elongation, Young's modulus and Poisson's ratio, for this material.



This printout displays the cyclic stress curve for 7010 T 76. The experimental values are shown as □ and the theoretical values, calculated by *Peenstress,* as a dotted line. The plastic deformation zone of most interest is at the knee of the curve and is about 1%.

Fig. 1b Behavior Curve



Peenstress software calculates and displays the stress profile and the calculated shot velocity. The separate panel indicates the surface stress *Σs*, the maximum stress *Σm*, the minimum depth of the maximum stress *PΣm* and the depth of compression *PΣ0*

Fig. 2a Residual Stress Distribution

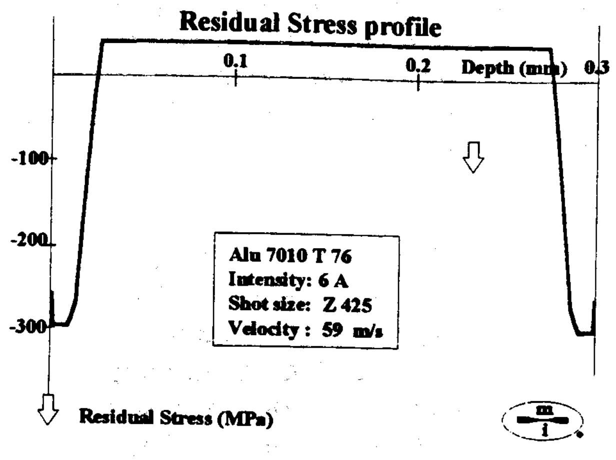


Fig. 2b Stress Distribution in Thin Plate

When the selected structure is a thin plate, the stress profile shows tensile stress compensating for the compressive stress below the surface, that is induced by the shot peening. In the illustration, the structure is a 3 mm thick plate, peened on both sides with equal parameters. If the peening intensity is too high, excessive tensile stress may be generated internally that will have a negative effect on fatigue.

SELECTION OF SHOT PEENING PARAMETERS

As an example, we have chosen the parameters selected in a recent study by Professor Ericsson, of the University of Linkoping, Sweden (figure 1a and 1b). The metal is 7010 T 76 aluminum for which we have both the monotonic and cyclic yield strengths and the residual stress readings resulting from peening with ceramic shot to the following set of conditions:

Z 425 Ceramic Beads - 6A intensity - 125% Peenscan® coverage

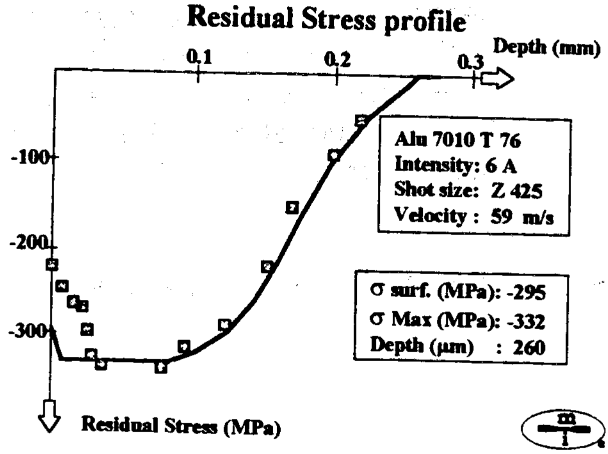


Fig. 3 Experimental values

SUPERIMPOSITION OF EXPERIMENTAL READINGS

Since we have available actual residual stress readings from Professor Ericsson's work for known shot peening conditions, we can superimpose readings over the curve modeled by *Peenstress*. This is illustrated by Figure 3, for alloy 7010 T 76 peened with ceramic beads and we can see that the magnitude of the stress and its depth are correctly reproduced by the *Peenstress* software. The distortion of the stress at the surface is principally the result of friction at the instant of impact and to the high deformation rate in the first few microns beneath the surface.

EFFECTS OF RESIDUAL STRESS ON FATIGUE

The simplest way to understand the effect of residual stresses on fatigue is by using a Haigh Diagram. If we apply a mean stress σn and an alternating stress σa to a part, the residual stress will have the same effect as an additional mean stress, σr. The metal is therefore subjected to as a maximum stress σmax, which is easily calculated:

$$\sigma max = \sigma n + \sigma a + \sigma r$$

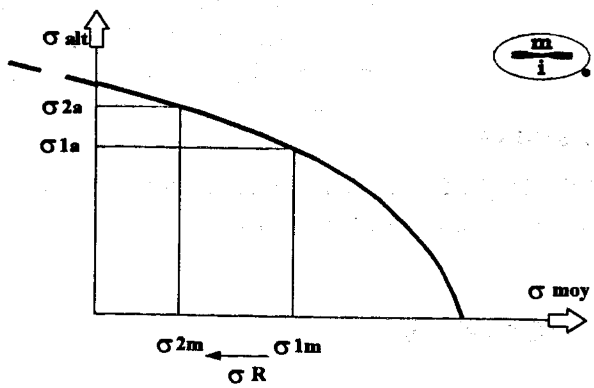


Fig. 4 Haigh Diagram

Notice that the residual stress will alter the mean stress applied to the specimen. The Haigh Diagram in Figure 4 shows the beneficial influence of a compressive residual stress. The reduction in the mean stress allows for a greater alternating load, thereby increasing the endurance limit. In simpler terms, the applied load in tension must first overcome the residual stress in compression before a fatigue failure can occur. Since all fatigue failures occur only in tension, the applied load would have to be greater than the yield strength of the material to overcome the residual compression from shot peening, before the part would fail. Only very rarely are applied loads beyond the yield of the material so that, in just about all cases, shot peening will increase the life of a part by many times.

Another way to illustrate the influence of residual stresses on fatigue is shown in Figure 5. The fatigue limit is shown as a function of the residual stress for a high strength steel. When the residual stress changes from +400 MPa to -800 MPa, the fatigue limit increases from 400 MPa to 1300 MPa. We have seen that the reduction in the mean stress increases the fatigue life. Using shot peening to introduce residual compressive stress is a very effective way to bring about this reduction in the mean stress. However, one of the difficulties is to define the optimum depth and magnitude of compression required to provide maximum fatigue strength increase for a given part and material. Another difficulty is to predict the residual stress induced by shot peening. **This is where *Peenstress* can help!**

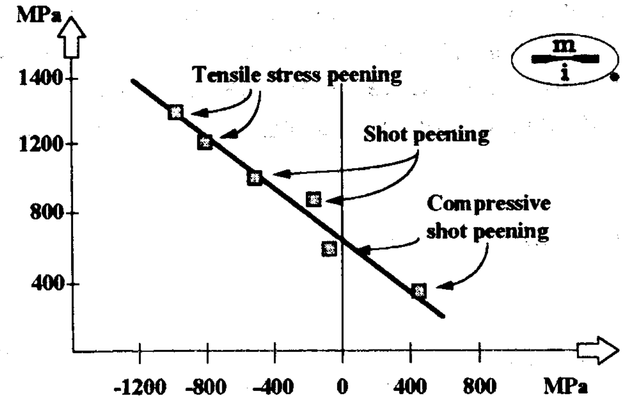


Fig. 5 Fatigue limit Vs residual stress

Tensile stress peening: Shot peening performed on part under tensile loading. This process is used to enhance fatigue life of springs and torsion bars, for instance.

Conventional shot peening: Shot peening performed without any applied load to the part during peening.

Compressive shot peening: Shot peening performed under compressive loading. Tough theoretically possible, there are no known applications.

EXAMPLES OF *PEENSTRESS* APPLICATIONS

As we have seen above, the modeling of the compressive stresses introduced by shot peening has become a necessary tool in designing for fatigue. The following cases are based on experience developed by Metal Improvement Company, Inc. during two years of extensive use of the *Peenstress* program.

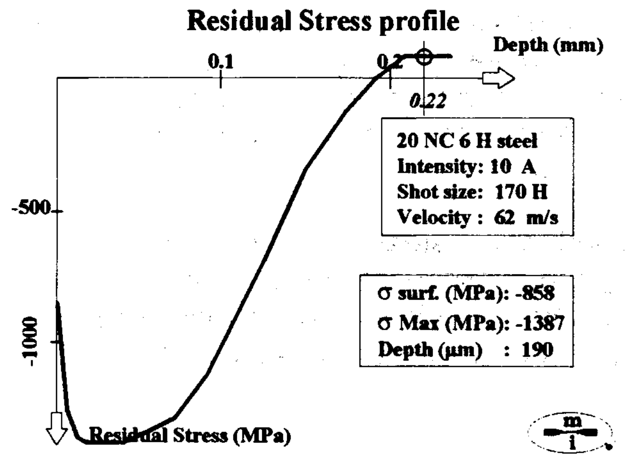
Case history # 1

Background: Pinion gears in a transmission are failing prematurely from spalling on the tooth faces as the result of contact fatigue. Pinions are carburized and the spalling initiates beneath the surface, which is 60 to 62 HRC.

Comments: Calculations show the depth of the maximum service Hertz stress to be 0.22 mm. Shot peening can correct the spalling problem by introducing compressive stresses at least as deep. The surface roughness should not be unduly affected by the peening, even though hard shot will be used, since the hardness of the gear pressure faces is very high.

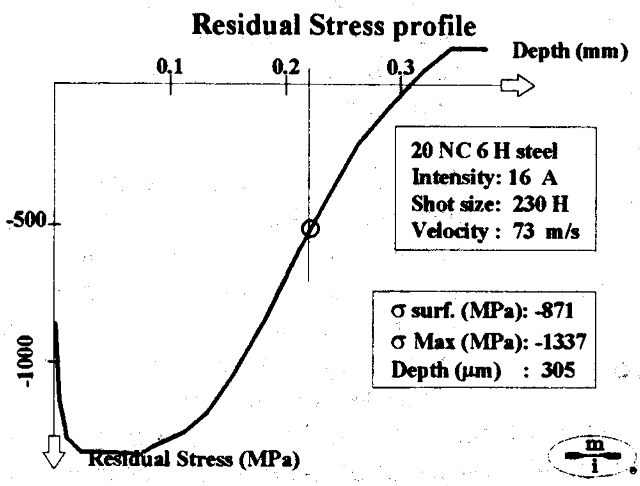
Modeling: The modeling shown in Figure 6 is for the residual stresses resulting from shot peening at the typical parameters used for tooth bending fatigue with this type of gear, that is:

MI 170 H shot - 10 A intensity - 150 % Peenscan® coverage



However, from the computer modeling (Figure 6), we can see that at the depth of the maximum Hertz stress (0.22 mm), the shot peening will actually produce a residual stress in tension of +100 MPa, which is very far from the ideal!

Fig. 6 predicted stress profile with typical SP parameters



By increasing the size of the shot and the Almen intensity, *Peenstress* tells us we can create a residual compressive stress of -500 MPa at the max. Hertz stress depth (Figure 7). The new call-out becomes:

MI 230 H shot - 16 A intensity - 150 % Peenscan® coverage

Fig. 7 Optimized stress profile

Interestingly, one can reasonably expect that the surface roughness will still be acceptable since the velocity of the shot remains close to that of the previous call-out (73 m/s compared to 62) so the depth of the dimple will not change appreciably.

Case History # 2

Background: The turbine blades and discs for jet engines are made of nickel base alloys, designed to resist high operating temperature of around 700°C. Inconel 718 is a typical alloy used for this purpose. When we have to shot peen the thin airfoils of turbine blades, there is always a risk of developing high and detrimental tensile stresses in the core of the airfoils. In this particular case, the blade is only 2 mm thick in the shot peened area and we will have to peen both sides to balance the stresses and maintain the original airfoil contour.

Comments: Airfoils are often peened with steel shot because they are decontaminated to remove iron during the subsequent coating processes. In the Metal Improvement Company technical library, we have a chart that illustrates the residual stress curve for Inconel 718 peened with MI 230 R shot, at 12 A with 125 % Peenscan® coverage.

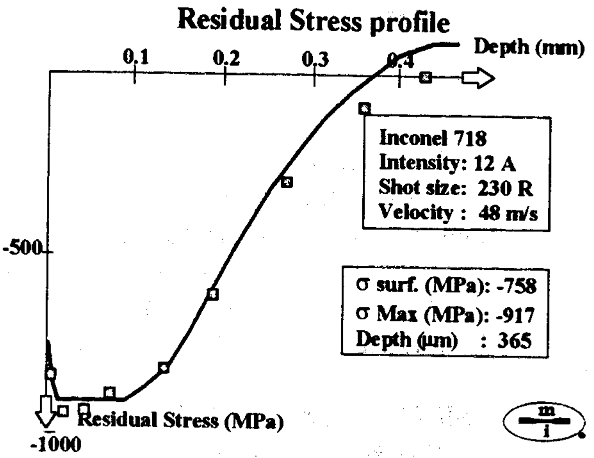


Fig. 8 Typical Residual Stress Profile

We can compare the actual residual stress profile after shot peening to the *Peenstress* modeling, using the same process parameters. The test results were obtained by x-ray diffraction.

At MIC, we normally seek to limit the depth of compression for thin sections to 10 % of the thickness so as not to develop excessive internal tensile stresses. In the preceding example, the depth of compression is 0.365 mm, which is too much for the blade thickness. The intensity is too high but reducing the intensity while keeping the same relatively large shot size will increase the peening exposure time and therefore also the cost of processing. A better solution is to change the call-out to the following;

MI 170 R shot - 8 A intensity - 125 % Peenscan® coverage

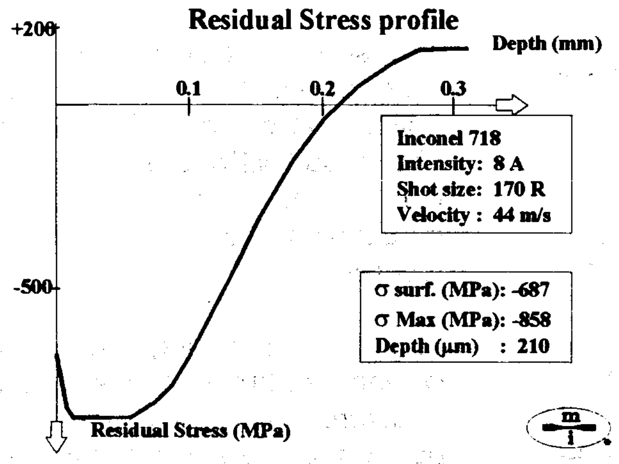


Fig. 9 Optimum Stress Profile

Shot size has been reduced to MI 170 and the velocity is only 44m/s so that the resulting surface finish will likely be acceptable. The depth of compression is now 0.2 mm or 10 % of the thickness. The residual tensile stress in the core is at an acceptable level of less that +100 MPa, while the compression is at about -800 MPa.

Case History # 3

Background: Some aircraft components are hollow forged titanium structures, formed at thigh temperatures and diffusion welded. These components are highly loaded and must be resistant to fatigue damage. Titanium responds very well to shot peening but these particular components, because of their hermetically sealed hollow core, can only be peened from the outside, leaving the inside surfaces subject to corresponding tensile stresses. For the shot peening to be effective, we must strictly limit these tensile stresses to acceptable levels. For this example, we will consider a hollow structure with wall thickness of only 1mm, fabricated from Titanium Ti4A6V alloy.

The design engineer will accept a tensile stress, created by the shot peening, that does not exceed +50 MPa on the internal surfaces. If the internal surface stress becomes greater than this limit, the fatigue resistance decreases because of the internally initiating failures and the effect of shot peening becomes negative. Engineering is also specifying peening with water-borne glass beads to restrict the surface finish and to avoid any iron contamination, as these parts will not be decontaminated after peening.

Comments: In MIC's technical library, we have a residual stress distribution curve for Ti4A6V Titanium, peened to the following call-out:

MI 110 R shot - 5 A intensity - 125 % Peenscan® coverage

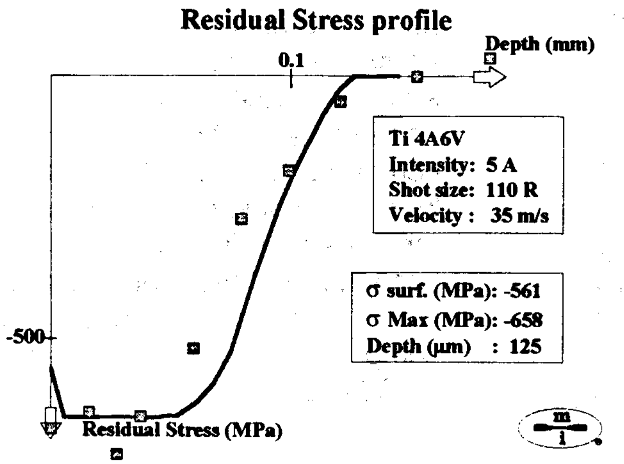
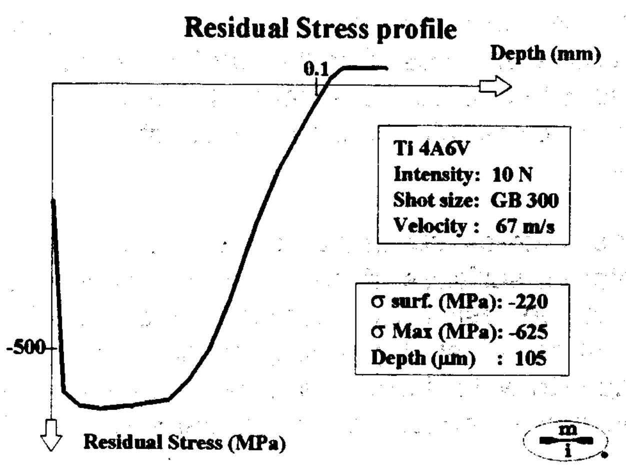


Fig. 10 Typical Stress Profile

The shot velocity is very low in order to preserve a good surface finish. The compressive stress is about -650 MPa and the depth is 0.15 mm. The *Peenstress* modeling is compatible with the test results.

The above modeling is for a thick component but when we select a structure only 1 mm thick, shot peened to the same parameters, the internal tensile stress becomes too high (approx. 100 MPa). Using the same glass beads but at a lower intensity, *Peenstress* shows we can meet the engineering requirements. The new parameters become:

GB 300 glass beads - 10 N intensity - 125 % Peenscan® coverage



The velocity of the glass beads is calculated to be 67m/s and the depth of compression shows at 0.1 mm in either direction. *Rt* is tangential and *Rz* is longitudinal direction. The magnitude of the tensile stress is on the order of +50 MPa, as required.

Fig. 11
Optimum Stress Profile

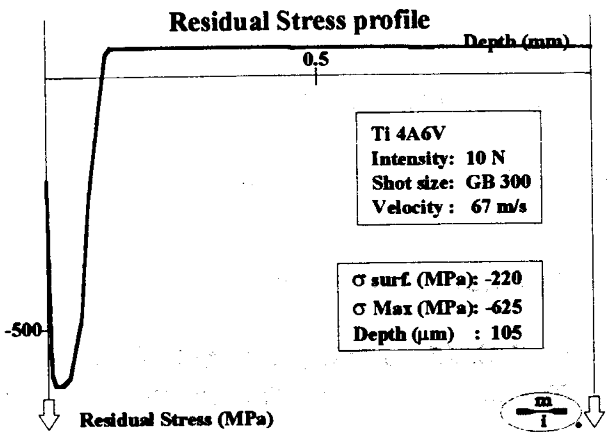


Fig. 12 Stress Profile Through Section

In this view, we can see the stress profile through the entire 1 mm cross section. The right hand side of the chart represents the peened surface. On the opposite surface, the maximum residual tensile stress is about +50 MPa and remains constant throughout the cross-section, except for the compressively stressed layer. The two stresses, Rz and Rt are different because we selected, for our model, a round tube with a 1 mm wall thickness. This explains why the two stresses at 90° vary slightly from each other. In the case of a flat plate, peened without deformation, the two values would be identical.

CONCLUSION

The ability to predict the residual stress effects from shot peening is a very effective tool in the selection of the optimum parameters for a given part and material. However, we should not forget that stresses are not the only influence upon fatigue and other types of metal failures. We have to take care not to generate flaws, either before, during or even after peening, such as micro-cracks, burrs, poor surface finishing, tears, pits, etc., that can negate the beneficial effects of residual compression.

In all cases, residual stress modeling should be verified by x-ray diffraction or other validation methods. The geometry of the part, the angle of impingement, the degree of coverage and the redistribution of stresses after loading, can all influence the stress profile.

Another important element is the relaxation of stresses under excessive loads and/or high temperatures. We are currently working on this subject with ENSAM and a software called *Optipeen* is in the prototype stage. It may be the subject of a future article.

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