SHOT PEENING - A COMPLEX PROCESS

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INTRODUCTION

Shot peening is a well known, well documented cold working process used to increase the resistance of metal parts against fatigue, fretting fatigue, corrosion fatigue, stress corrosion cracking, etc. It is gaining ever wider acceptance and generating more and more interest. However, although a lot has been done in the past ten years to understand why and how it works, a lot more remains to be explained. This paper intends to review the present state of the art.

SHOT PEENING EFFECTS

In shot peening, the surface of a finished metal part is bombarded with high speed spherical media (cast steel shot, glass bead, ceramic media etc.) Every piece of media acts as a tiny peening hammer. The major effect associated with this peening action is the introduction in the surface layer of a residual compressive stress, essentially biaxial and isotropic in planes parallel to the surface. The insertion of residual compressive stresses is known to be one of the most effective ways of prolonging fatigue life (fig. 1) (réf. 1)

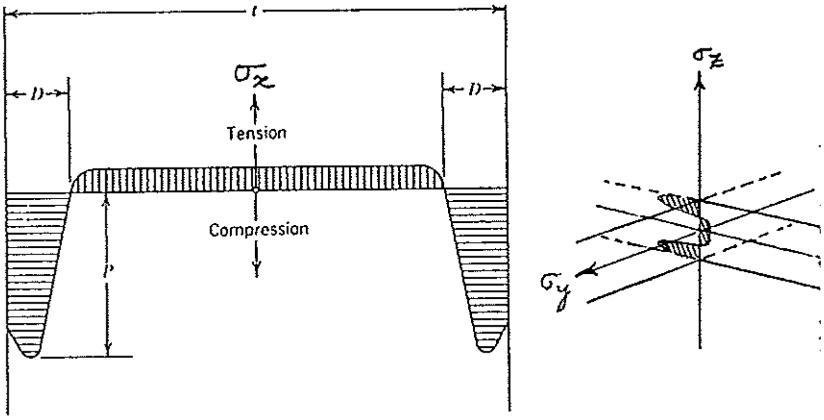


fig. 1
Typical distribution, in plane (x,z), of residual stresses in a plate shot peened on both faces. Distribution in the (y,z) plane would be identical.
t : plate thickness
D : depth of compressive stress
P : peak magnitude of compressive stress.

However, this effect cannot be dissociated from other alterations resulting from the process which also affect fatigue properties : mechanical properties of surface material due to cold working, geometrical surface effects such as roughness modifications, metallurgical and microstructural changes etc. When trying to evaluate the influence of shot peening on fatigue properties, the effect of the coverage rate and the decay of residual stresses in service should also be taken into account. The interaction of these various parameters and their relative importance vary with the material studied, prior manufacturing processes as well as the quality and adequate control of peening itself. This explains why the apparently very simple method of shot peening qualifies as a very complex process indeed.

PRODUCTION OF RESIDUAL COMPRESSIVE STRESSES

According to Wohlfahrt (ref. 2), the generation of residual stresses by shot peening results from two different, simultaneous and competing actions.

One is the direct plastic elongation of layers very close to the surface as a consequence of tangential forces caused by the impacts.

This stretching process is a function of the amount of cold working at the surface and more or less proportional to the surface roughness increase.

The second residual stress generating process is due to the production of a plastic elongation caused by biaxial shear stresses at a depth.

$$Z_{max} = 0.47\ a \qquad \text{(a ; radius of shot peening dimple upon impact)}$$

This maximum shear stress is caused by the Hertzian pressure associated with the normal forces caused by the impacts (fig. 2)

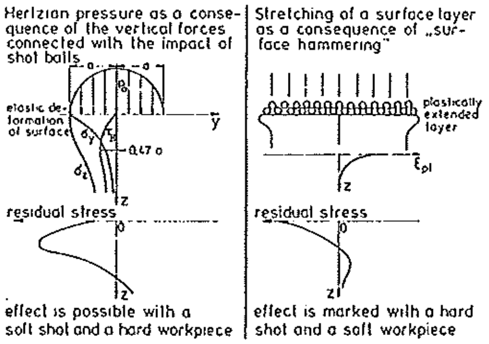


Fig. 2 Schematic illustration of the formation of residual stresses as a consequence of two competitiveprocesses in shot peening : hertzian pressure (left) and direct stretching of a surface layer (right)

Wolfahrt's theory, which is relatively recent (1983), explains most variations in the shape of stress profiles and is widely accepted today.

PREDICTION OF RESIDUAL STRESSES BY MODELING

As currently available methods do not allow non destructive measuring of residual stresses below the surface, attempts were made to develop models for predicting the distribution of shot peening stresses.

L. Castex et al (réf. 3) developed such a model based on Wohlfahrt's Hertzian pressure theory and on Zarka's method (ref. 3) which consists in determining the residual stress field from the elastic stress field given by Hertz's theory. Castex's method considers shot peening as a cyclic loading of the surface and takes the following parameters into consideration : material characteristics (in particular cyclic yield strength), shot material (cast steel, ceramic, glass etc.), shot size and shot velocity. (fig. 3)

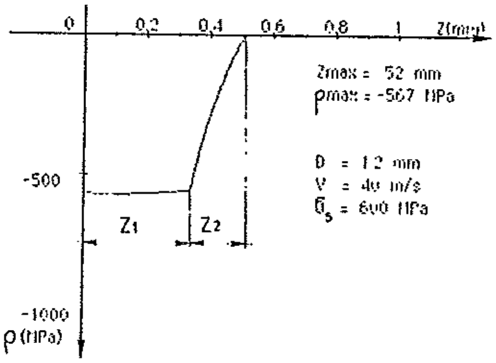


fig.3 Curves of residual stress as a function of depth

Although close agreement was found between "residual stress vs depth" curves given by the model and experimental results on several materials (fig. 4), the program is currently being developed further to include Wohlfahrt's surface stretching effect, the influence of coverage, as well as the elastic plastic behavior of various materials(aluminum alloys, nickel base alloys) where experimental results demonstrate the need to refine the method.

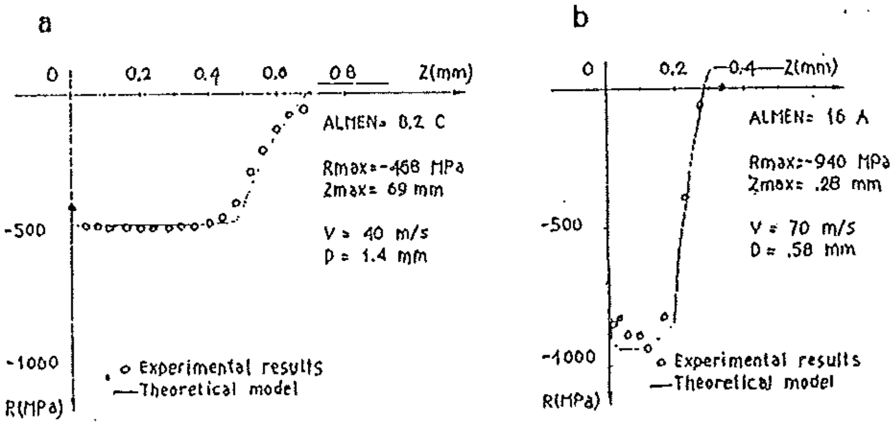


fig 4 "Residual stress versus depth" curves for E 460 (a) and TA 6V (b)

EFFECT OF SHOT PEENING RESIDUAL STRESSES ON FATIGUE AND OTHER CRAK PROPAGATING FAILURES

The residual compressive stresses introduced by peening generate a confined compressive stress field which opposes cracking. This effect is twofold : an increase in the resistance to the formation of micro-cracks, in other words a retardation of crack initiation and a slowing down or prevention of crack growth. The latter effect is more important than the former.

As the interior material is not exposed to atmosphere or accidental damage, it is more resistant than the surface to damage. Fatigue fractures below the surface may happen if the tensile stress below the surface is higher than the fatigue limit of smooth specimens.

The peak value of the compressive residual stress, P in fig. 1, depends mainly on the material of the peened parts and on the restraints imposed on the part (stress peening). In a part peened without restraint, the value of P is of the order of half the yield strength of the material.

Changing the peening parameters (shot velocity and shot size) will change mainly the width of the peak and the depth (D in fig. 1)

MODERN SHOT PEENING TECHNOLOGY

Shot peening has generated more and more interest during the last ten years. Today, it is well recognized as a powerful technology in helping to enhance the resistance of materials against various kinds of stress induced damage. The benefits which can be derived from shot peening have been widely documented.

In the past however, shot peening has been used traditionally as a fix to be applied when other methods had failed and many applications still exist today where "just an improvement" in fatigue properties was deemed sufficient and no effort was made to look for optimum specifications and optimum results. (ref. 4)

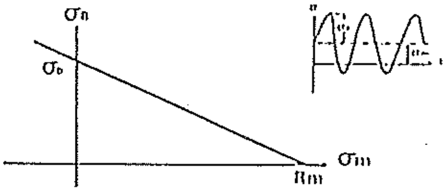
More recently, the emphasis, both in industry and in the academic world, has been placed on understanding the process in depth in order to be able to :

- Predict the effect of given shot peening parameters on the fatigue strength/life of components.
- Select the optimum parameters to obtain the maximum life enhancement.
- Implement flawless parameters controls to assure optimum improvement repeatability.

1.) FORECASTING THE FATIGUE LIFE OF SHOT PEENED COMPONENTS

a.) The most traditional method (ref. 5) consists in measuring or estimating the residual stress at the surface, or estimating the maximum stress below the surface and considering that the effect of a residual stress is similar to that of a mean stress. Then, from the standpoint of compressive residual stresses, a prediction of the fatigue strength at 10^7 cycles can be done on Goodman or Haigh type diagrams with relations such as Morrow's formula. (fig. 5)

$$\sigma_a = \sigma_D - \alpha(\sigma_m + \sigma_R)$$



$$\sigma_a = \sigma_D - \frac{\sigma_D}{R_m} \cdot \underbrace{\sigma_m}_{\sigma_m + \sigma_R}$$

Figure 5 taken from Flavenot J.F. 9eJournée Nationale sur le Grenaillage de Précontrainte Senlis, Nov 27, 1985, CETIM

With σ_a Critical alternating stress
σ_D Fatigue strength at 10^7 cycles at 0 mean stress
σ_m Mean stress
σ_R Residual stress

At 0 mean stress (reversed loading) this becomes : $\sigma_a = \sigma_D - \alpha\,\sigma_R$

Further, the fatigue strength at intermediate fatigue lives can be plotted on straight line log-log SN curves.

Yet, this method is oversimple. Actual test data show that simply summing up residual stresses and load stresses cannot serve as an accurate base for predicting the effect of shot peening on fatigue life, for the following reasons :

1 - Residual stresses are multiaxial.
Multiaxial fatigue criteria have been proposed. Some are more satisfactory than others (Dang Van and Crossland). None are really practical.

2 - Stress distribution, depth and gradient.
These factors are not taken into account in spite of their considerable influence.

3 - Stress relief.
Residual compressive stresses are not stable when submitted to repeated loads. Forecasting should integrate a stabilized stress level as a function of load.

4 - Metallurgical effects.
Shot peening produces workhardening, affects grain size, retained austenite etc. These parameters, in turn, affect fatigue behavior.

5 - Geometrical effects.
Shot peening has far more effect on notched parts, on crackprone or on rough surfaces. Shot peening will positively affect weld toe notch factor, small radii etc.

6 - Influence of coverage.

Coverage is defined as the ratio between the shot idented areas and the total surface requiring peening. Any coverage lower than 100 % is associated with uneven residual stress distribution Test data show that full coverage (100 % or more) is essential to a good, reliable, reproducible peening operation.

Furthermore, some materials require coverages higher than 1 to achieve saturation. Others show continuous fatigue behavior improvement with increased coverages (e.g. titanium TA6V)

b.) A more refined approach derived from the above is to consider the influence of the distribution in depth of shot peening residual stresses on the local fatigue strength of components. (fig. 6) (ref. 6)

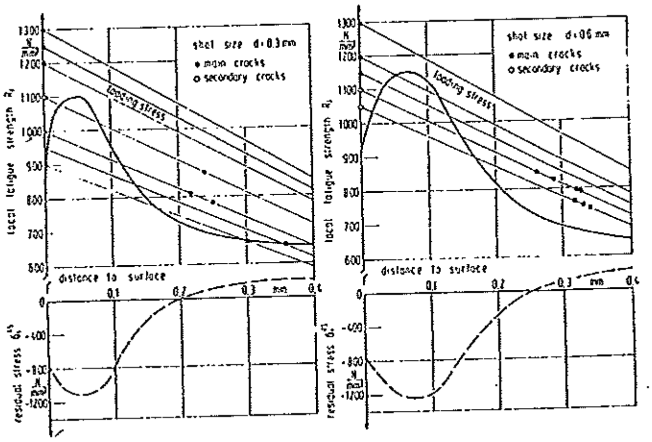


Fig. 6
Local fatigue strengths near the surface of shot peened bending specimens calculated according to the Goodman relation and experimentally determined crack sites.

Then consider the distribution of load stresses. Failures under uniaxial loading have been reasonably well predicted by this method which integrates residual stress and load stress distribution and gradient, including the influence of notches and stress raisers.

Associating this method with the Castex method of predicting residual stresses should give interesting results and a study funded by Metal Improvement Company is currently under way at ENSAM under the direction of Professor Castex. The computer program incorporating this approach as well as many other new aspects of material cyclic behavior and shot peening effects, should be available within the next two or three years.

c.) Biaxial fatigue testing is fairly common especially in the form of alternating torsion and torsion bending tests. Forecasting the fatigue strength of shot peened torsion and torsion bending specimens or even simple parts can be done by replacing Goodman or Haigh diagrams by biaxial criteria such as Gough and Pollard's, for instance. (fig. 7) (ref. 7)

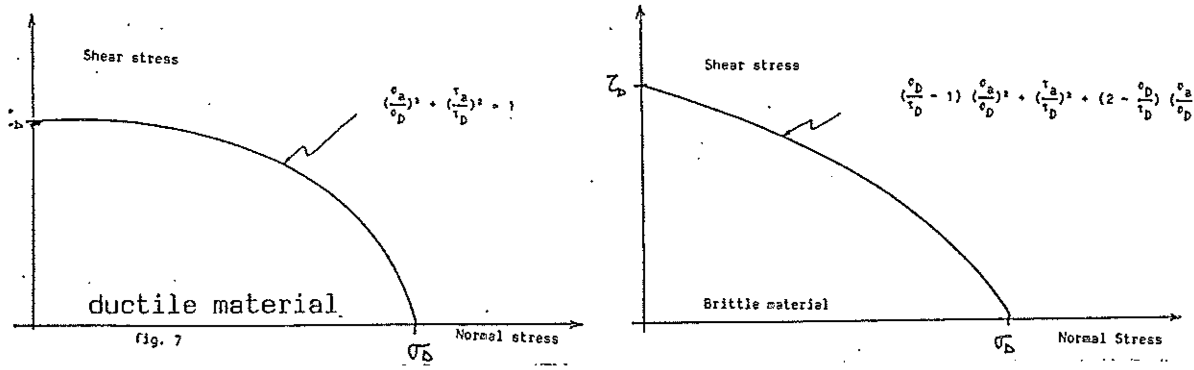


fig. 7

Unfortunately, most limitations listed under a.) above for the Goodman and Haigh methods also apply here. Very little in the way of comparisons with actual experimental data is to be found in existing litterature.

d.) Considering that shot peening induced stresses are biaxial and that most actual fatigue problems are caused by multiaxial loading stresses, many authors have attempted to use multiaxial fatigue criteria.

There are several criteria available but most authors agree that shot peening effects are best illustrated by Crossland's criterion.

$$(\sigma_{eq})_a + B.p_{max} \leqslant A$$

or Dang Van's criterion

$$\tau_a + B'.p_{max} \leqslant A'$$

if we consider $\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{12} & \sigma_{22} & \sigma_{23} \\ \sigma_{13} & \sigma_{23} & \sigma_{33} \end{bmatrix}$ The tensor of local stresses acting on a given point 0

Then $J_2 = \frac{1}{6}\left[(\sigma_{11}-\sigma_{22})^2 + (\sigma_{11}-\sigma_{33})^2 + (\sigma_{22}-\sigma_{33})^2 + 6\sigma_{12}^2 + 6\sigma_{23}^2 + 6\sigma_{13}^2\right]$

is one of the invariants associated with the tensor in case of angular rotations around point O.

Then :

$$\sigma_{eq} = \sqrt{3 J_2} \quad \text{(von Mises)}$$

Physically, σ_{eq} is the expression of the distortion energy associated with σ.

In Dang Van's criterion, σ_{eq} is replaced by τ_{max} which is the maximum shearing stress acting in a principal plane normal to the hydrostatic pressure axis.

In triaxial criteria, stresses are assumed to vary in phase. Hence, for any time t, we can write :

$$\sigma_{eq}(t) = \sigma_{eq}(m) + \sigma_{eq}(a) .\sin\ t$$

$$\tau_{max}(t) = \tau_{max}(m) + \tau_{max}(a) .\sin\ t$$

$\sigma_{eq}(m)$ and $\tau_{max}(m)$ are the mean values

$\sigma_{eq}(a)$ and $\tau_{max}(a)$ are the stress amplitudes

In both criteria, P_{max} is the maximum hydrostatic pressure.
Coefficients A, B, A' and B' must be determined by experimentation.

Both criteria can be illustrated by straight line diagrams similar to Haigh's
Example : figures 8,9 and 10 (ref. 8)

Fig. 8 shows the residual stress tensors of shot peened 4Ni-Cr (35 NCD 16) grade steel specimens as measured by X ray diffraction. The cylindrical test specimens were later submitted to fatigue testing. Some specimens were also subjected to destructive testing in order to measure the stress profiles (fig. 9). The Dang Van diagram was also plotted. (fig. 10)

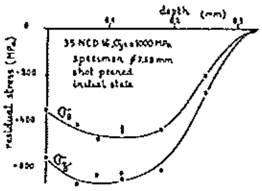
Fig. 8 Surface residual stress tensors on the different specimen types

	rotating-bending	tension-compression	alternate-torsion	bending-torsion
. Grinding	$\begin{array}{ccc} \theta & \underline{z} & r \\ -180 & 0 & 0 \\ 0 & -50 & 40 \\ 0 & -40 & 0 \end{array}$	$\begin{array}{ccc} \theta & \underline{z} & r \\ -170 & 0 & 0 \\ 0 & 50 & 40 \\ 0 & -40 & 0 \end{array}$	$\begin{array}{ccc} \underline{\theta} & z & r \\ -100 & 0 & 20 \\ 0 & -300 & 0 \\ -20 & 0 & 0 \end{array}$	$\begin{array}{ccc} \theta & \underline{z} & r \\ -210 & 10 & 0 \\ 10 & 0 & 50 \\ 0 & -50 & 0 \end{array}$
. Shot peening	$\begin{array}{ccc} \theta & \underline{z} & r \\ -380 & 0 & 0 \\ 0 & -600 & 0 \\ 0 & 0 & 0 \end{array}$	$\begin{array}{ccc} \theta & \underline{z} & r \\ -450 & 0 & 0 \\ 0 & -570 & 0 \\ 0 & 0 & 0 \end{array}$	$\begin{array}{ccc} \underline{\theta} & z & r \\ -400 & 0 & 0 \\ 0 & -580 & 0 \\ 0 & 0 & 0 \end{array}$	$\begin{array}{ccc} \theta & \underline{z} & r \\ -360 & 0 & 0 \\ 0 & -600 & 0 \\ 0 & 0 & 0 \end{array}$

N.B. All values are given in MPa. The underlined coordinate corresponds to the direction of grinding.

θ : tangential stresses - z : axial stresses - r : radial stresses.

fig. 9 Residual stress field introduced by shot peening.



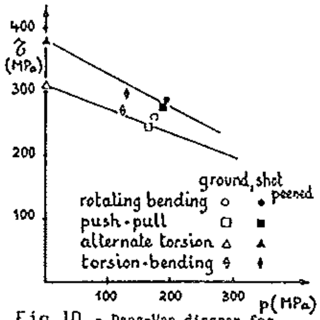


Fig.10 - Dang-Van diagram for 35 NCD 16 steel subjected to grinding and shot peening.

Discussion :

- The tensors show that although grinding may introduce compressive stresses, these residual stresses are much lower than those produced by shot peening and in some cases tensile stresses may also be generated.

- It is obvious that the peening stresses in this case are not isotropic this is due to the use of small cylindrical fatigue specimens where circumferential stresses are always smaller than axial stresses. Note that several other shot peening conditions, like the use of nozzles makin(a shallow angle with the peened surface may also generate anisotropic residual stresses.

- One of the author's comment about the Dang Van diagram is that it was plotted for ground and shot peened 35 NCD 16 steel for the loadings he investigated and that it can then be used for any type of multiaxial loading. From a practical standpoint, this logical comment calls for the following remarks :

* The use of Dang Van, or of any other multiaxial criteria is fairly cumbersome and time consuming. It should reasonably be restricted to studies including actual multiaxial testing.

* In the case of rotating bending and push pull tests, Haigh or Goodman would have yielded similar results.

* In the case of alternate torsion and torsion bending Gough and Pollard would have been sufficient.

* We can appreciate that once it is plotted, the Dang Van diagram can be used for any type of multiaxial loading, however this is quite academic as multiaxial testing is expensive and, hence, very uncommon and although actual parts are often subjected to multiaxial loading, the variable loads are seldom in phase. In this case, experimentation shows that multiaxial criteria are not satisfactory.

e.) In many cases, the actual fatigue behavior of shot peened specimens and all the more of actual components is not in line with anticipations based on residual stresses. Not only does this demonstrate the need to verify calculations by mean of fatigue tests, but it also shows that it is necessary to consider all the variables affected by shot peening and their stability under fatigue loading. The influence of these parameters varies with the material, with the shot peening conditions and the type of loading. The objective of this paper is not to deal in detail with all these considerations which are already mentioned in prior chapters.

However, the following examples should be sufficient to illustrate some of these influences as well as the complexity of the process.

<u>Surface roughness</u> (ref. 9)

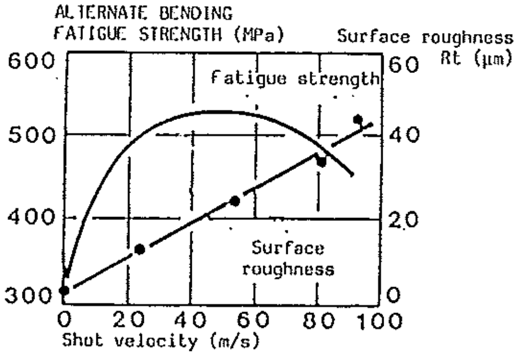


Fig. 11 - QUENCHED 16 Mn Cr 5 Steel Grade

Fig. 11 illustrates the detrimental effect of surface roughness competing with the beneficial effect of residual stresses.

Cold working (ref. 9)

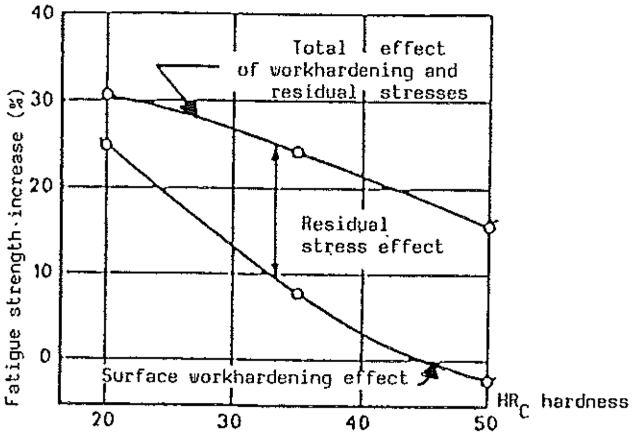


Fig. 12 illustrates the relative influence on fatigue strength of compressive residual stresses and surface work-hardening as a function of workpiece hardness.

Metallurgical and microstructural changes

These changes, grain refinement, high dislocation density, elimination of residual austenite, etc. are usually beneficial. However, some specific cases, where production of highly crackprone surfaces was generated by the martensitic tranformation have been reported.

Residual stress relaxation

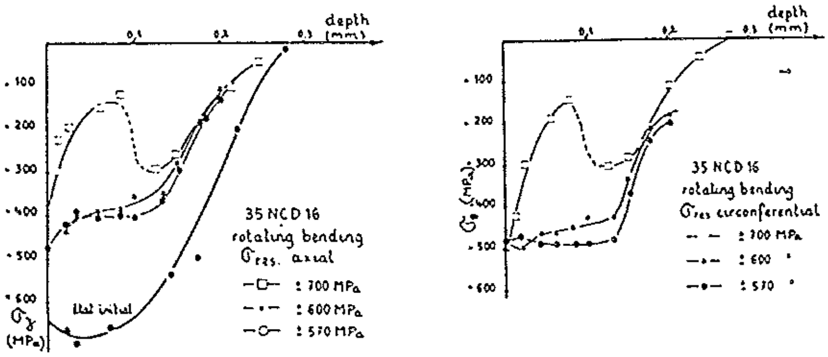


Fig. 13- Variation of axial and circumferential residual stresses in depth under rotating bending loading.

Fig. 13 illustrates the relaxation of axial shot peening residual stresses, for the 35 NCD 16 steel grade specimens discussed in 1.) d.) (ref. 8). This variation, after 100 cycles in rotating bending under stress amplitudes of 550, 600 and 700 MPa was measured by X ray diffraction and destructive testing.

Comments :

- The depth of compression remains unchanged.
- This material softens considerably under fatigue loading.
- The major relaxation occurs during the first cycles. Eventually, the residual stresses will stabilize at a level which depends on their intial value, the applied stress and the cyclic yield strength. 35 NCD 16 grade though , tends to soften gradually and stabilization is delayed.
- The cyclic yield strength in this case stabilizes around 660 MPa. Any applied stress above 660 MPa will eventually lead to complete relief.
- The endurance limit of 35 NCD 16 tested in rotating bending was raised about 10%. A very small increase compared with the calculated increase : 23% (Dang Van).

2.) OPTIMUM SHOT PEENING PARAMETERS SELECTION

This problem is of the same nature as that of forecasting fatigue life except that it is even more complex.

When we try to predict fatigue life, or strength of a component, we are basically attempting to resolve a general equation of the type :

$$R_D = f(C,L,S)$$

for given values of C,L and S.

With R_D = fatigue strength at 10^7 cycles.

C = variable associated with the component. (material, shape, manufacturing, stresses, surface finish before peening etc.)

L = variable associated with the type of loading.

S = variable associated with the shot peening parameters (shot material and hardness shot size, shot velocity or Almen intensity, coverage etc.)

Now if we consider :

$$R_D = f(C,L,S) = f_1\ (S)$$

for a given component under given loading conditions, experience shows that there generally are some specific peening conditions which satisfy.

$$R_{Dmax} = f_1(S_{op}) \text{ or } S_{op} = \varphi(R_{Dmax})$$

with R_{Dmax} = maximum fatigue strength

S_{op} = optimum shot peening parameters.

The solution of this problem is extremely interesting both to in-industry and the academic world.

In spite of the great amount of recent activity, developments and innovations in the field of shot peening, we can well imagine, from the preceding chapter, how complex the problem is.

There is no precise, mathematical answer to it.

Considering the complexity of the problem, most current development work rightly restricts itself to studying one aspect of optimization at a time, e.g. coverage optimization, optimum shot hardness for a specific material etc.

First, as an example, let us mention H.O. Fuchs' paper (ref. 10) on optimum peening intensities. In this article, he develops a fairly complex formula which can be summarized as follow :

$\omega = f(\alpha, \beta, \delta)$ where ω is the increase in fatigue strentgh
α and β are coefficients depending on the material
δ is the depth of compression.(wich can be easily converted to Almen intensity)

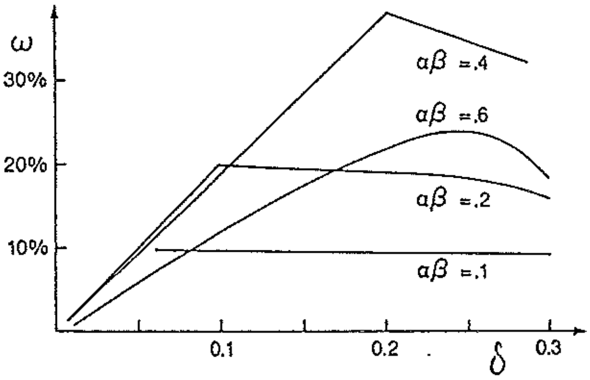


Fig. 14 - Increase of fatigue resistance as a function of relative depth of compressive stress for several values of the product $\alpha\beta$

fig. 14 is an illustration of the function for several values of the product $\alpha\beta$. Each curve shows a maximum value of ω for a specific optimum depth of compression.

From a practical standpoint, this calculation which is based, among other asumptions, on the local fatigue strength distribution concept (see 1.) b.) is interesting and in agreement with many test results, although its applicability to such materials as aluminum alloys, titanium and nickel base alloys is not discussed in the paper.

Metal Improvement Company is currently developing a computer program based on this method and is considering the possibility of integrating it together with the Ensam stress distribution model in one single program.

The method however has its limitations :

* It considers only stresses and leaves out all other shot peening effects.

* It also leaves out Wohlfahrt's concept of residual stress generation and the formulation it uses to express stress distribution vs depth is approximate. This drawback will be eliminated when the formulation is replaced by Castex's model in the new program.

* It is based on uniaxial criteria (Haigh, Morrow) and its accuracy may be questioned for biaxial loading (alternate torsion for instance)

* It also assumes that cracks are stopped by compressive stresses (non propagating cracks) which is often true but not always, the phenomenon of short crack propagation being the subject of hot debates among experts today.

* Of course, it does not solve the problem of shot size, shot material and hardness and coverage selection.

For engineers in the industry, the general problem of optimum parameters remains,and the lack of guidelines with respect to their selection is a major stumbling block.

However, experienced users of the process have developed considerable know-how over the years which they draw on to resolve problems due to this lack of formal rules.

The following chart (ref. 11) is an example of how practical know-how can be summarized to serve as a tool for users of the process. (fig. 15)

Materials \ Parameters	Steel shot		Ceramic shot		Glass beads		Almen Intensity			Coverage rate			
Special conditions	hard	regula	dry	wet	dry	wet	low	medium	high	100% to 200%	200% to 400%	400% to 600%	till 1000%
Low hardness steel	+	++	+	--	+	--	+	++	++	+	++	+	+
High hardness steel	++	-	++	--	+	--	++	++	+	++	++	+	-
Low alloy steel e.g. : 4135	-	++	-	-	+	-	++	+	--	++	-	--	--
Alloy steel e.g. : 13% CR	++	+			+		++	++	+	++	+	+	-
Titanium e.g. : Ti 6-4	+	++	-	++	--	++	++	++	-	++	+	+	-
Aluminum alloy e.g. : 2000 series	+	++	+	++	+	++	++	+	--	++	-	--	--
Aluminum alloy e. g. : 7000 series	+	++	+	++	+	++	++	++	+	++	-	--	--
Base Nickel e.g. : Inconel 718	+	++	-		+	+	++	+	-	++	++	+	+

\+ Possible
++ Recommended
\- Not advisable
-- Forbidden

▱ lack of reference

RECOMMENDED SHOT PEENING PARAMETERS FOR MISCELLANEOUS MATERIALS

Guidelines of this nature should of course be used with caution. They have no pretense beyond being the summary of a compilation of data from many sources.

3.) SHOT PEENING CONTROLS

The philosophy of optimum improvement has evolved because components today are subjected to higher stresses under far more severe conditions, as weight saving and cost efficiency objectives are becoming more prevalent than ever.

Selecting optimum parameters provides no assurance that optimum improvement will be attained unless flawless process controls are implemented to assure process repeatability.

Let us briefly review the main shot peening controls available today, keeping in mind that no current nondestructive technique is to be found to verify that shot peening has been done correctly.

a.) Almen intensity

The intensity is an indication of the kinetic energy transfer in the peening process. The Almen intensity works on the principle that if a flat piece of metal is clamped on a solid block and exposed to a blast of shot, it will be curved upon removal from the block. The height of the curved arc serves as a measure of intensity. The Almen system involves standard test strips of three different thickness called A, C, or N (1.29, 2.39, 0.79 mm)and a standard measuring device, called the Almen gage. The Almen intensity specification consists of a number (arc height) and a letter (A, C or N), for instance 10C.

Although the Almen intensity alone is not sufficient to define the results of a peening process, it is the main parameter which should be observed to assure repeatability. The principal advantage of the Almen intensity is that it integrates most relevant factors (shot velocity, mass and hardness, angle of impingement etc.)

The depth of compression is directly proportionnal to the Almen intensity. (see fig. 1 and comments p.5)

b.) Shot peening media (ref. 12)

Ideally, the media impinging on the surface of components should be at, or near, normal angles to the surface and be perfect spheres creating a minimum of surface damage. However, recognizing that perfect spheres are not always practicable, the following illustration (fig. 16) (ref. 12) shows the type of shapes that are considered to be acceptable. Shot should be preconditioned prior to use so as to remove any undesirable shapes as well as scale or sharp edges. The shot peening machinery must be equipped with shot size and shape control system that would remove undesirable particles during the operation, delivering only media of the quality shown in fig. 16 to the workpiece. Investigations are currently proceeding to develop new spherical media which does not readily break down and will yield minimum surface damage during the peening operation. The use of good media in the process is of paramount importance, and without it, precise control of the other three variables becomes superfluous.

Acceptable Shapes (Ref. 1)

Fig 16 Approximate magnification 10X.

c.) Complete coverage

Coverage was defined and its importance discussed earlier. The use of fluorescent tracers for determining uniform and/or complete coverage has gained wide acceptance in the last decade and is the preferred method for assuring shot peening coverage. A minimum of 100 % coverage is of paramount importance to assure a uniform depth of compressive stress in extending fatigue life as well as retarding the phenomena of stress corrosion cracking. When fluorescent tracer systems are unavailable, the use of 10X magnification on the piece part is an acceptable alternate. However, it is less reliable and takes additional time of skilled quality assurance personnel.

d.) Computer controls

When the user is assured of good quality shot media, intensity and coverage verification, he can then address the control of all critical variables within the peening cabinet to assure repeatability in using the process as a design tool. The computer controls and records the following data within the shot peen cabinet :

- A. Shot flow
- B. Air pressure
- C. Air flow
- D. Wheel speed
- E. Amperage of wheel motor
- F. Movement of wheel and/or nozzles
- G. Angles of nozzles (when robotics are used)
- H. Movement or rotation of the workpiece
- I. The oscillation (of nozzles or wheel) including variable speed programs
- J. Sequential shut down of nozzles or wheel (fig. 17)(ref. 12)
- K. Peening time

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CUSTOMER                                    AIR PRESS TIME   5   SEC          OSCILLATION PROGRAM             NOZZLE PROGRAM TUE 5:39:47 PM
PART NUMBER                                 SHOT FLOW TIME  15   SEC        POS      DWELL     POS     DWELL  NOZZ  ACTIVE   JUL 31, 1984
                                            TURNTABLE TIME   5   SEC  HOME  1 20.0   32.0   11  19.5   20.0    1  20.00 A
SPECIFICATION    MIL-S-13165B AMEND NO 2    SPEED CHANGE     5   SEC  START 2 21.0    4.0   12  19.0   21.0    2  20.00 A
OPERATION        .                          MAX SHOT FLOW   25   LBS        3 23.5    8.0   13  18.5   22.0    3  20.00 A
                                            TURNTABLE RPM   16.0 RPM        4 23.0   12.0   14  18.0   23.0    4  20.00 A
M/C PROCEDURE    017                                                        5 22.5   14.0   15  17.5   24.0    5  40.00 A
SHOT SIZE        MI-170R                    MODE           NORM             6 22.0   15.0   16  17.0   25.0    6  40.00 A
INTENSITY        6-10A                      CYCLE COUNT    NA               7 21.5   16.0   17  12.0   25.0    7  40.00 A
COVERAGE         100%                       CYCLE TIME     60:00            8 21.0   17.0   18  12.0   25.0    8  60.00 A  REMAINING
SATURATION TIME  8 MINUTES                                                  9 20.5   18.0   19  12.0   25.0    9  60.00 A   CYCLES
100% COVER TIME  6 MINUTES                                                 10 20.0   19.0   1A  12.0           10  60.00 A     0

          NOZZ  01 NOZZ  02 NOZZ  03 NOZZ  04 NOZZ  05 NOZZ  06 NOZZ  07 NOZZ  08 NOZZ  09 NOZZ  10 TURNTABLE  OSCILL  OSCILL
                                                                                                     SPEED     SPEED  POSITION
          AIR .SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT AIR  SHOT
          PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M PSI  LB/M   RPM      IN/MIN  INCHES
HI LIMIT  60   18.0 60   18.0 60   18.0 60   15.0 60   18.0 60   18.0 60   18.0 40   16.0 40   16.0 40   15.0   11.0     + 2.0

DATA      55   16.0 55   16.0 55   16.0 55   16.0 55   16.0 55   16.0 55   16.0 35   14.0 35   14.0 35   14.0   10.0       6.0

LO LIMIT  50 . 14.0 50   14.0 50   14.0 50   14.0 50   14.0 50   14.0 50   14.0 30   12.0 30   12.0 30   12.0    9.0       2.0

S/O001    55   14.0 56   16.0 55   15.0 55   14.0 56   15.0 58   14.0 57   15.0 35   13.0 34   14.0 34   14.0   10.0       6.0
S/O002    ABORT 1 14 10 LOW SHOT FLOW NOZZ 07 AT 12 LB/MIN
S/O002    56   15.0 56   15.0 57   17.0 56   15.0 57   16.0 55   15.0 54   15.0 36   14.0 34   13.0 34   14.0    9.5       5.0
```

Fig. 17 : Typical printout of one lot of
components requiring shot peening

e.) Peening as a tool for designers

Shot peening can be used to :

1. prolong component life (fatigue strength improvement between 20 and 70 %).
2. Increase stress load for the same life.
3. Allow size and weight reductions
4. Reduce need for fine machining.
5. Reduce costs by application of any of the above
6. Enable use of higher strentgh steels without fear of notch
7. Enable use of manufacturing processes detrimental to fatigue i.e. EDM, ECM, hard chromium plating, etc.

From a designer's viewpoint, shot peening would be a perfect tool if it could safely allow a specific increase of the design stress without affecting the factor of safety by introducing added uncertainties. The designer would then be able to select specific shot peening parameters to achieve a given permissible stress increase.

However, we have seen that the relationship between shot peening variables and fatigue life or strength is far from simple. This explains why today, a typical designer's approach will be essentially practical and will involve fatigue testing at the early stage of the design. As a matter of example, we may propose the following pattern :

1 - Shot peen test specimens with various peening parameters.
2 - Fatigue test specimens ; peened and unpeened. Select optimum peening parameters.
3 - Design part using permissible stress estimated from 2.
4 - Confirm fatigue data on prototype parts ; peened and unpeened.
5 - Specify shot peening parameters.
6 - confirm fatigue data on first production parts.

Control of all the variables assures the designer of desired process control and typically the above program is established. The shot peening of the prototype component is closely controlled by computers so that the same program can be used on production machinery thereby assuring fatigue performance of production shot peened components as well. In the past, this had never been possible. However, with the aid of the computers, design engineering personnel can confirm to industry and their various inspection and government authorities that life enhancement through the use of controlled shot peening is viable tool.

THE FUTURE (ref. 4)

As we look into the future for shot peening and its technology (fig. 18) we see the need for improved peening media, with improved life and improved fracture characteristics. We see the need for finilization of the engineering models and equations which will yield optimum peening parameters : [objective : $R_{Dmax} = f\ (S_{op})$]

FUTURE NEEDS

1. Improved Media
2. Engineering Models/Equations
3. Nondestructive Test to Measure Residual Stress
4. Education of All Industries on Available Peening Technology

Fig. 18

We see the need for a non destructive technique to measure the peening effect. And the last of the needs, and certainly not the least importa is the education of all industries on available peening technology. There are still people in many industries that don't know about shot peening or the benefits that can be achieve by shot peening. A good deal of education of the metalworking industry is still needed.

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