ACADEMIC STUDY
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Back to Basics
Advances in Shot Peening

INTRODUCTION

Shot peening has advanced steadily since its first introduction. This article concentrates on the advances made in the last forty years. Those advances have allowed shot peening to become the smart technological process that it is today. Most of the advances would not have been possible without the corresponding explosion of computing power and availability of sophisticated computer software.

The overall objective is to present a coherent account of the most important, and relatively recent, advances in shot peening. Every advance can be viewed as satisfying a perceived need. For example, intensity measurement used to be very subjective, with different values being quoted by different individuals. The need was for a technique that reduced this measurement variability. Computer-based methods have satisfied this need.

PEENING INTENSITY

A notable advance has been the realization that a plot of Almen arc heights against peening time can be represented by a mathematical equation. Arc height is given as being a function of peening time. Fig.1 illustrates this feature, using the excellent data presented by Wieland (Proc. ICSP5, 1993, Table 4, page 36). In fig.1, a four-component equation has been computer-fitted. The equation has dominant constants, a, b and c, but also has a small linear constant:

$$\mathbf{h = a\,(1 - exp(-b{*}t^{c})) + d{*}t} \qquad (1)$$

where **h** is Almen arc height, **t** is peening time.

Once the best-fitting constants have been found we can plot the curve. The use of four-component equations does ensure a very close fit. Equation (2) is a simpler exponential equation as it has three, rather than four, components.

$$\mathbf{h = a\,(1 - exp(-b{*}t^{c}))} \qquad (2)$$

The three-component equation (2) still gives a close fit as shown by fig.2. For comparison purposes the four-component equation appears as a very faint curve.

Today's specification requirement is that peening intensity is the arc height which increases by precisely 10% when the peening time is doubled. This requirement can be derived mathematically. For equation (2), derivation is achieved by minimising the function **f(t)**:

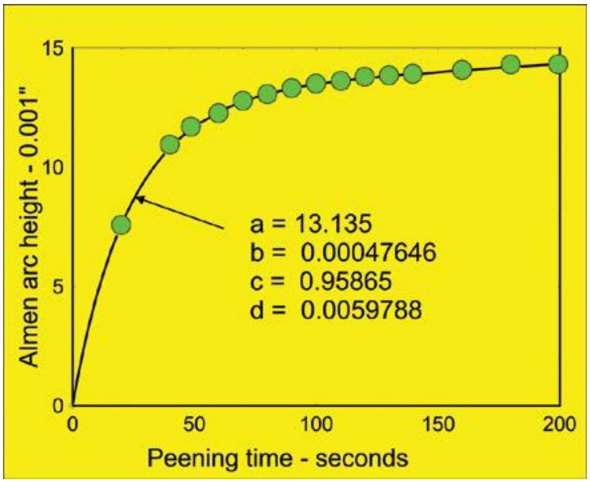

Fig.1 Curve fit of equation (1) using Wieland's data.

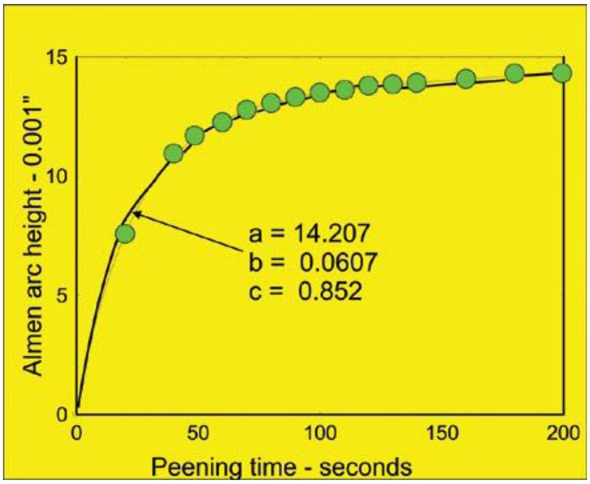

Fig.2 Curve fit of equation (2) using Wieland's data.

$$\mathbf{f(t) = 1.1a(1 - exp\,(-b{*}t^{c})) - a(1 - exp(-b{*}(2t)^{c}))} \qquad (3)$$

The value of t that minimises the equation is known as **T**. Substituting this derived value into equation (2) gives us the required peening intensity value, **H**. Available computer-based programs do all of the maths for us, thank goodness.

ALMEN STRIPS AND GAGES

Almen Strips

An important advance in shot peening relates to strip quality. Measurements of arc height induced in peened Almen strips inevitably involves scatter. The degree of scatter depends, to some extent, on the quality of the Almen strips themselves. Fig.3 is a schematic representation of this effect. As strip quality increases, the degree of measurement scatter is reduced. Some scatter must remain, even with the highest quality of Almen strips.

Published variables affecting Almen strip quality include hardness, flatness (prebow) thickness and width. One variable that has not received sufficient attention is the elastic modulus, E, of the strip steel. Induced arc height depends directly on the elastic modulus of the strip. Elastic modulus can vary substantially because of preferred orientation, a.k.a., texture. As a side-line, the importance of preferred orientation in aero engine turbine blades was recognized many years ago. Rotating turbine blades resonate at a rotational speed that depends directly on the blades' elastic modulus. If this speed is allowed to be maintained, the blades become overstressed, due to excessive vibration—often leading to catastrophic engine failure. The solution is to avoid staying at any of the rotational speeds that would induce resonation.

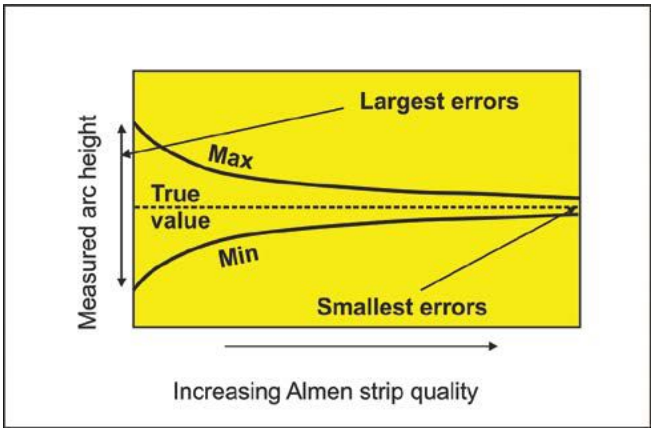

Fig.3. Effect of Almen strip quality on arc height measurements.

Another notable advance has been the introduction of miniature strips—appropriate when dealing with small peened areas.

Almen Gages

Dramatic advances have been made in the range and operational accuracy of Almen gages. Gages are now available specifically for non-magnetic Almen strips and for miniature Almen strips. Operational accuracy has been improved by incorporating end and back stops which enable precise strip location.

The most advanced gages have digital displays, convertible to either metric or Imperial units, magnetic hold-down on support balls and computer connectivity. Simpler and lighter gages are available that employ an analogue monitor. They retain magnetic hold-down but have only back stops.

Digital mini-strip Almen gages are now available that retain the features of the most advanced gages.

Aluminum-based, non-magnetic alloys are common in the aerospace industry. The benefits of shot peening for these alloys have become recognized. The industry therefore now requires advanced, accurate gages for arc height measurements. Aero-Almen strips are very thin and have only a third of the elastic modulus of steel. It follows that standard spring-loaded dial gage indicators can induce deflection. Non-contact sensors eliminate possible deflection.

Alternatives

The standard practice of using a set of Almen strips and post-mortem arc height measurement is somewhat tedious. Advances that have been proposed include using a single captive disc with a sensor positioned underneath, allowing continuous deflection measurement direct to a computer. Another proposal is to use a standard Almen strip with a thermocouple glued underneath— again allowing continuous measurement direct to a computer. Temperature rise caused by peening can be calibrated against standard practice curves.

COVERAGE

Coverage has previously been defined in SAE J2277 as "The percentage of a surface that has been impacted by the peening media. The minimum peening time required to obtain 100% coverage is determined by gradually increasing total peening time until the entire surface being peened exhibits overlapping dimpling. Coverages above 100% are multiples of the exposure time required to achieve 100% coverage." This definition is, to say the least, both vague and misleading!

Thankfully, the latest 2022 version of J2277 addresses some of these issues:

> "Coverage is the extent of peening as shown by the percentage of the surface exhibiting a uniform impact pattern of overlapping indentations. Coverage of exactly 100 percent exists only as a theoretical limit that is neither measurable or achievable. Coverage is considered full coverage (a.k.a. complete coverage) when 98 percent or more of the surface is indented. It is difficult to visually distinguish differences in coverage above 98 percent.
>
> Coverage, up to 100 percent, is defined as the percentage of a surface that has been impacted at least once by the peening media. Typically, coverage estimates are obtained by optically-aided visual inspection of the peened part. Estimates of coverage by visual observation are unavoidably subjective, particularly when full coverage is being approached."

The advances that have been made relating to coverage can be subdivided into (a) those improving our understanding of coverage progression and (b) those improving the precision and accuracy of our coverage measurements.

(a) Advances improving our understanding of coverage progression

The first significant advance was to appreciate that coverage must be dealt with on a statistical basis. As peening time is increased so the percentage coverage increases but in the form of an exponential curve. This is illustrated by fig.4. The most important points to note are (1) that the rate of coverage reduces rapidly with peening time because of more and more areas being already impacted and (2) that reported coverage is the average of dented and undented areas.

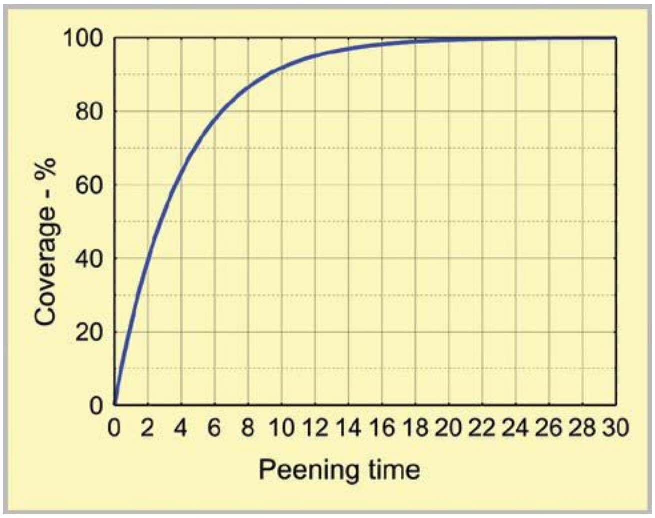

Fig.4. Effect of peening time on average coverage.

Fig.5 illustrates the second point. Scanning Line 1, we have a mixture of dented and undented areas. Deduced percentage coverage will vary with Line number. It follows that we must specify a large enough scan area to obtain an accurate average percentage coverage.

A very important advance was the realization that we should not be aiming at so-called "100% coverage". Fig. 6 illustrates this very important fact. Maximum improvement of component properties is achieved at significantly less than 100%. The optimum coverage to be aimed at depends on several component factors.

(b) Advances improving the precision and accuracy of coverage measurements

The precision of coverage measurement has advanced greatly with the introduction of new techniques. These have largely taken over from previous, highly subjective methods. At ICSP7 in San Francisco, an attendee showed me a peened Almen strip that was claimed to have 100% coverage. Even

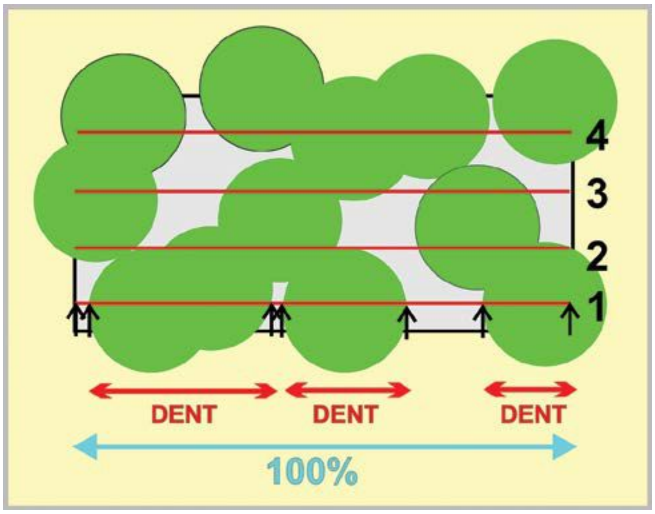

Fig.5. Coverage as a mixture of dented and undented areas.

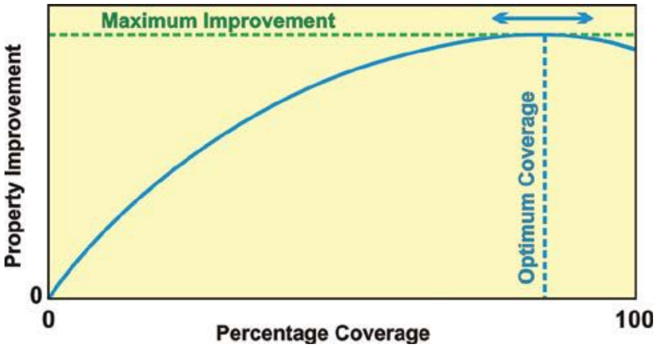

Fig.6. Example of optimum coverage.

with the naked eye it was obvious that coverage was less than 50%! Objective methods are based on the principle involved in fig.5. Coverage can be derived by the ratio of dented to undented lengths along lines marked on an enlarged photograph. Because the coverage varies from line to line, several line estimates have to be averaged. This can be very tedious! Image analysis techniques are now available that remove the tedium. It is even possible to invest in a dedicated, computer-based coverage estimate based on line intersections.

SHOT

Perhaps the most notable advance of shot is the widespread adoption of cut wire steel shot as an alternative to cast steel shot. The General Motor Corporation's Patent No. 667,815 issued 1st February 1950, covers "A new media known as Cut Wire Pellets." Curiously, however, B.C. Tilghman's U.K. Patent No. 3626, issued in 1872, states that he had used "grains made by cutting off short lengths of wire."

The main difference between cut wire and cast steel shot lies in the spread of size. Cut wire has a very narrow spread whereas cast shot size spread is only limited by specified sieving. As a consequence, dents made by cut wire shot tend to have a much narrower size spread than those made when using cast shot.

With increased awareness of the benefits of shot peening, a variety of chemical compositions of shot have been introduced. These include stainless steel (for peening aluminum as well as stainless steel), bronze (for peening some non-ferrous components), as well as refractory materials based on aluminum oxide (Al_2O_3) and glass.

Shot durability is a very important factor in overall peening costs. Carburized steel shot has been introduced to marry a tough core with a very hard, wear-resistant, surface layer.

SHOT VELOCITY

Advances have been made in quantifying the factors that influence shot velocity. These factors are obviously different for air blast compared with wheel blast peening.

(1) Air Blast Shot velocity

Equation (4) contains the factors that influence air blast shot velocity:

$$\mathbf{v_s = (1{\cdot}5.C_D.\rho_A.s/\pi.d.\rho_S)^{0.5}\,(v_a - v_s)} \qquad (4)$$

where $\mathbf{C_D}$ is the “drag coefficient” (a dimensionless number that depends upon the shape of the object and, for a smooth sphere, $\mathbf{C_D} \approx 0.5$), $\boldsymbol{\rho_A}$ is the density of the **compressed** air (1.2 kgm^{-3} times the compression ratio), **s** is the nozzle length, **d** is the shot diameter, $\boldsymbol{\rho_S}$ is the density of the shot, $\mathbf{v_a}$ is the velocity of the air stream and $\mathbf{v_s}$ is the velocity of the shot particle. ($\mathbf{v_a - v_s}$) is termed the “relative velocity” of the particle compared with that of the air stream.

Equation (4) may look complicated but in fact becomes very simple for a fixed peening setup. For round shot of a given density and diameter, accelerated in a nozzle of a given length, then the only variable is the density of the compressed air! In other words, we control the velocity of shot leaving the nozzle by varying the density of the compressed air in the nozzle.

The factors incorporated in equation (4) have interesting general significance. The drag coefficient, C_D, of a sphere is low, ≈ 0.5, whereas a flat surface has a value of 1.28. That explains why bullets and artillery shells are manufactured with a flat at the compression end—they are accelerated to much higher velocities than if they were cannonball shaped. The nozzle length, **s**, of a rifle is much longer than that of a pistol again allowing generation of much higher shot velocities. As the density of shot, $\boldsymbol{\rho_S}$, increases the shot velocity decreases —dense shot requiring more acceleration work. The same is true for shot diameter, **d**, so that artillery shells compensate by having very long barrels as on warships and tanks.

Fig.7 illustrates the advance made by understanding the importance of air density on shot acceleration. Analogously

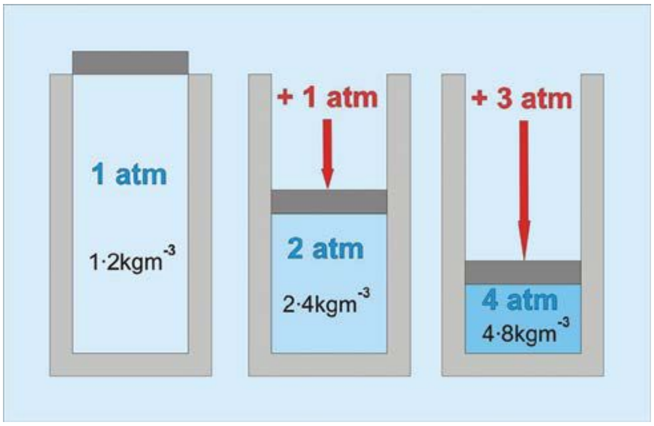

Fig.7. Density of compressed air increased by applied atmospheric pressure.

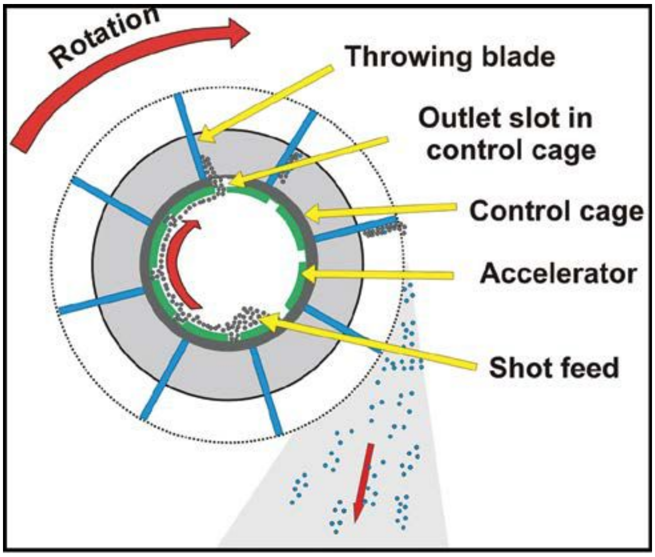

Fig.8. Basic components of a Wheel blast machine.

think of having to withstand fast-flowing fluid. The denser the fluid the more we would tend to be swept off our feet.

(2) Wheel Blast Shot velocity

Fig.8 shows the basic elements of a simple wheel blaster. Incremental advances in wheel blast equipment have been made. For example, Wheelabrator introduced their EZIFIT design in 2003. A major advance in understanding involves an equation that enables wheel blast shot velocity to be predicted and controlled:

$$\mathbf{V_S = 2.\pi.N(R^2 + 2RL - L^2)^{0.5}} \qquad (5)$$

Equation (5) looks complicated, but can easily be employed. For a given machine, the radius of the wheel, **R**, and the length of the blade are fixed, so that **N**, the speed of rotation in ms^{-1}, is the only variable. Hence, for example, when **R** = 0.4 m and **L** = 0.2 m, equation (5) simplifies to $\mathbf{V_S = 2.\pi.N.0.529}$ or $\mathbf{V_S}$

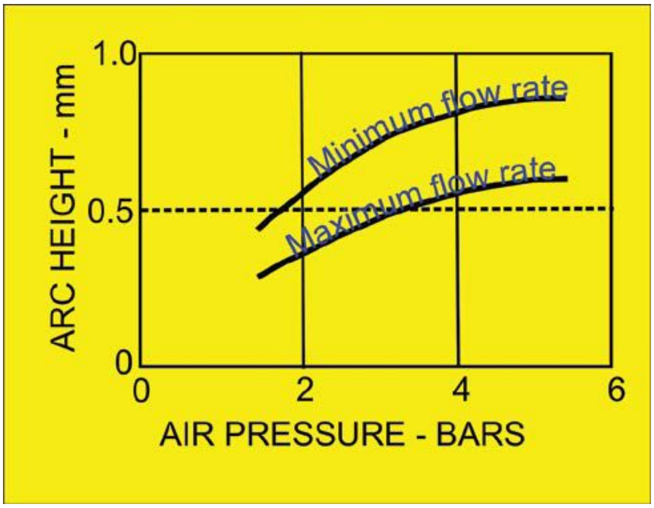

Fig.9. Effect of flow rate on Almen arc height.

= 0.324N. If **N = 300 ms^{-1}** the predicted shot velocity would therefore be **97.2 ms^{-1}**.

SHOT FLOW CONTROL and MONITORING

Great advances have been made in the control and monitoring of shot flow. These are of vital importance because they affect both coverage rate and peening intensity. Continuous monitoring of shot flow rate is now possible—achieved using either inductive sensors for ferrous shot or capacitive sensors for non-ferrous shot. Continuous monitoring goes hand in hand with continuous control of flow rate.

The advantage of being able to control and monitor shot flow is illustrated by fig.9. As the flow rate is increased, the velocity of outgoing shot is reduced. This is because more of the available work has to be done accelerating the shot. The observed effect of shot flow rate is substantial.

DISCUSSION

An attempt has been made to indicate the most important advances in shot peening that have been made in the last forty years. Apologies if any have been missed. Manufacturers always speak highly of new products. As in any sphere, it is a case of caveat emptor (buyer beware). There is no doubt, however, that many important advances in shot peening have been made and should be adopted. Progress is not static; more advances will be achieved in coming years. Tribal knowledge is important in identifying areas where new advances need to be made.

Blast Cleaning Technologies Announces the Acquisition of Coyote Enterprises, Inc.

BLAST CLEANING TECHNOLOGIES (BCT) has announced the acquisition of Coyote Enterprises, Inc. Blast Cleaning Technologies designs and manufactures equipment, components, and system upgrades that offer improved fit, function, and life.

Under the new ownership of Blast Cleaning Technologies, Coyote customers will now have access to North America's largest engineering and field service team as well as BCT's quality and inventory support. The operation will be consolidated and centralized into the Blast Cleaning Technologies 140,000 sq. ft. manufacturing facility located in West Allis, Wisconsin.

Coyote Enterprises Inc. was founded in 1998 by Jim and Cindy Goff to provide cost effective blast equipment and competitively priced replacement parts engineered for increased performance and longevity. Coyote was built on this vision to design a variety of cost effective yet innovative shot blast machines. That vision became Coyote.

"This is an important acquisition for us," Carl Panzenhagen, President and CEO of Blast Cleaning Technologies said. "The addition of this product line compliments and expands our current product line, allowing us to support both current and new customers, positioning us for continued growth in the Shot Blasting Industry."

About Blast Cleaning Technologies

Blast Cleaning Technologies has become the fastest growing shot blast manufacturer over the last several years by investing in engineering, manufacturing, research, and development.

BCT was founded on repairing, rebuilding, and upgrading equipment and offering thousands of competitively priced, quality blast parts. Partnering with industry-leading technology suppliers, BCT provides unmatched equipment, service and support for the foundry, forging, metal fabrication, automotive, aerospace, agriculture, defense, rail, energy and power generation industries, and other special applications.

About Coyote Enterprises, Inc.

Coyote Enterprises was founded in 1998 by Jim and Cindy Goff. Jim is a pioneer in the blast industry beginning in 1965 at Wheelabrator. In 1969 he was hired by R.T. Nelson to design and build the first portable shot blasting machine. Jim accomplished this task and was awarded a patent for this machine named "Bertha" in September 1972. His vision for new and innovative Abrasive Shot Blast Cleaning and Peening Equipment was just beginning. In 1973, Jim founded the Goff Corporation located in Seminole, Oklahoma which he privately owned and operated successfully for 18 years until he chose to sell it in 1991.