ACADEMIC STUDY
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Questions for Shot Peeners

INTRODUCTION

Shot peeners are often asked a variety of questions relating to shot peening. These give us opportunities to expand the knowledge of the questioners. Our answers must, however, be based on each questioner's current knowledge. It would be pointless to "blind them with science."

This article is based on the author's own experience of fielding questions. It starts with very basic questions appropriate for the "general public." Later questions are perhaps more appropriate for attendees at shot peening workshops.

Of necessity, the article reflects a very personal approach. As such, I cannot claim any particular merit for any of the answers. They should be regarded simply as guidelines.

QUESTIONS AND POSSIBLE ANSWERS

Q1: "What is shot peening ?"
A1: "Millions of hard, near-spherical particles, are fired at the surface of engineering parts—mainly of moving vehicles such as airplanes, tanks, submarines and cars. It is similar to what happens with a shot gun. The main difference is that we use a continuous stream of high-velocity shot particles rather than firing a one-off bullet."

Q2: "Why is shot peening useful?"
A2: "Shot-peened engineering components last very much longer than if they had not been shot peened. Most components are nowadays designed with minimum weight. This means that they will only last for a specified time before fractures occur. If some idiot had forgotten to have vital components shot peened the vehicle will crash prematurely!"

Q3: "Why does shot peening increase component life?"
A3: "Shot peening does two useful things to the component. The first is that it work-hardens a thin layer of the component's surface. Secondly, it induces beneficial compressive residual stresses in the surface layer. Both of these help to stop cracks forming at the surface."

Q4: "Why is compressive residual stress useful?"
A4: "It helps to stop cracks forming at the surface. Let's use an analogy. Imagine the rubber sleeve on, say, a hockey stick. The rubber is stretched tightly over the handle. This means that we have a tensile residual stress situation in the rubber sleeve. If we were to cut through the rubber using a safety razor blade, as in A of fig.1, the tension in the rubber would cause it to pull apart, as in B. If, magically, the rubber was being in a state of compression the rubber would not pull apart. The compressed surface layer produced by shot peening offsets applied tensile stresses."

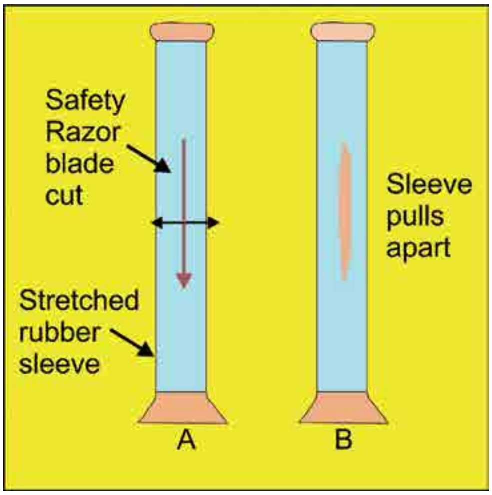

Fig.1. Analogy using rubber sleeve failure.

Q5: "What sort of improvement does shot peening impart?"
A5: "Moving vehicles have lots of components. They are subject to alternating stresses. If the alternating stresses are high enough, component failure will occur by what's called "Fatigue". Metallic components are made up of atoms arranged in a regular pattern as crystals. When the metal is pushed and pulled millions of times the crystals get tired of having to resist. Getting tired of the work involved is synonymous with the word "Fatigue". It simply gives up by forming cracks that cause the component to break apart so that no applied alternating stresses have to be endured. Shot peening introduces a surface layer that resists failure by fatigue."

Q6: "How much improvement does shot peening impart?"
A6: "We can quantify the amount of improvement using graphs. Before that, consider individual components subjected to fatigue stressing. Imagine that the designers have worked out that an unpeened component will last for only 100 hours of fatigue stressing before failure. With shot peening, tests show that the component will now survive for at least 20,000 hours of fatigue stressing—Eureka! If the component only has to last 5,000 hours before being replaced, fatigue failure is averted by shot peening.

Improvement is illustrated quantitatively by fig.2. Look at point **A** for an alternating applied stress of four (arbitrary) units. Fatigue failure is predicted to occur after 10,000 applied alternating stress cycles for unpeened component. Peened components are, however, predicted to last ten times as long—100,000 cycles. Now consider point **B** with a lower applied alternating stress level of three units. Peened components are now predicted to last indefinitely at this stress level whereas unpeened components are predicted to fail after about 100,000 cycles.

The region marked as **HS** in fig.2 represents very high applied alternating stress levels. Failure is then imminent!"

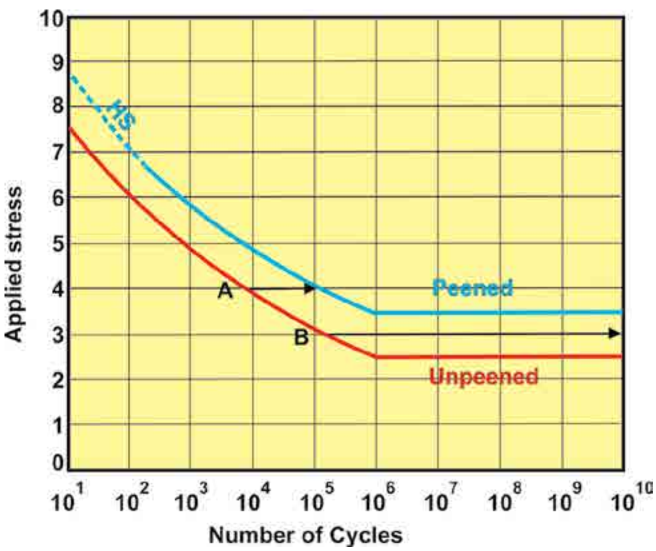

Fig.2. Fatigue curves for carbon steels.

Q7: "How thick is the protective surface layer produced by shot peening ?"

A7: "It depends on the size of the dent that each particle produces. Imagine dropping a ball onto a block of modelling clay. The size of the dent depends on three factors: (1) the size of the ball, (2) the height that we drop it from and (3) the density of the ball. Larger balls, greater heights and larger densities would all increase the size of the dent.

Size, drop height and density all affect the kinetic energy of the ball. Quantitatively, kinetic energy, K.E., is calculated from the equation:

$$K.E. = m.v^2/2$$

Where **m** is the mass of the ball and **v** is its velocity. **m** is proportional to the cube of the shot particle's diameter but is only simply proportional to its diameter. It follows that a range of shot sizes is very useful from producing different sizes of dent. Fig.3 illustrates available standard steel shot sizes. The largest is almost twenty times greater in diameter than is the smallest. For the same velocity, the largest shot will have 8,000 times the kinetic energy of the smallest shot. Combining shot size and shot velocity gives excellent control of dent sizes."

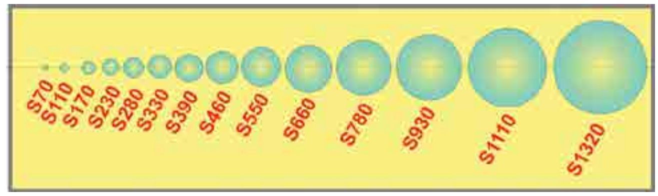

Fig.3. Size range of cast steel shot.

Q8: "Why does denting of a component produce a surface layer that is in compressive residual stress?"

A8: "The impacting shot particles each produce a dent. As a dent is being produced material is pushed outwards. The surface layer resists this movement, pushing inwards. (Newton's Third Law states that when two bodies interact, they apply forces on one another that are equal in magnitude and opposite in direction.) The situation is illustrated by fig.4.

Formation of a dent tends to stretch and bend the component. Resisting this bending puts the surface into compression. Millions of tiny contributions of compression add up to a surface layer that contains compressive residual stress."

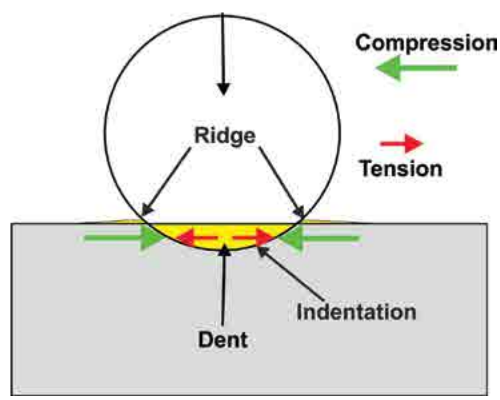

Fig.4. Dent setting up resisting forces.

Q9: "How many dents are needed to produce an effective protective surface layer?"

A9: "That is probably the biggest, most complicated, question that can be asked about shot peening. Essentially, the number of dents required depends on both the size of the component and on the average size of the dents. We use a term called "coverage" that accommodates both of these variables. Fig.5 models what we are looking for. Six dents centered in the unit square would correspond to a low coverage. Twenty-four identical dents would give medium coverage.

The proportion of area covered by dents is termed "Percentage coverage".

Next, we have to consider what percentage coverage is the most effective. We also have to ensure that we can measure coverage with reasonable accuracy. Coverage does not increase linearly with peening time. That is because the dents start to overlap more and more with increased peening. Overlapping is shown for the twenty-four dents in fig.5. The

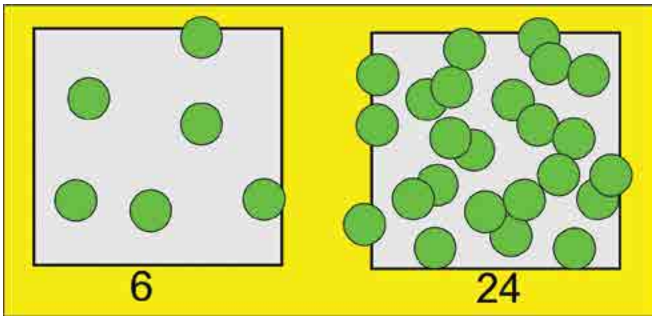

Fig.5. Model of low and medium dent coverage.

overlapping areas do not contribute to coverage. Probability of overlapping increases with coverage.

We use coverage as an indication of the optimum amount of peening that should be applied to a given component.

Theory tells us that coverage increase with peening time should follow an exponential curve as illustrated in fig.6. 98% coverage is shown in fig.6 as occurring at a relative peening time of eight units. This is significant because it has been agreed that 98% coverage is the greatest that can be measured with acceptable accuracy. 98% coverage is now termed "Full coverage."

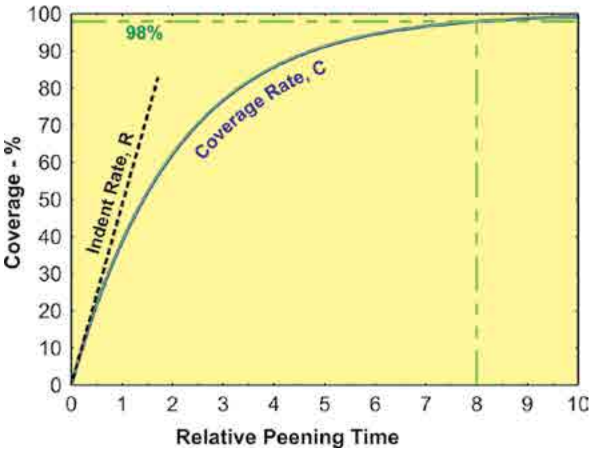

Fig.6. Coverage increase with increase in peening time.

We use coverage as an indication of the optimum amount of peening that should be applied to a given component. The most effective amount of coverage depends on the component. Too little coverage would leave regions unprotected. Too much coverage would run the risk of surface damage with fig.7 showing why. **n** is the number of overlaps. The peening time units are nominal. After one, about 28% of the 37% coverage consists of dents having just one overlap. At 98% coverage only 6% has received just one overlapping area. 40% has received either three or four overlaps. About 2% of the component has dents that have been impacted nine times!"

The equation for coverage versus peening time is:

$$\mathbf{C = 100(1 - exp(-\pi D^2/4.R.t))} \qquad (1)$$

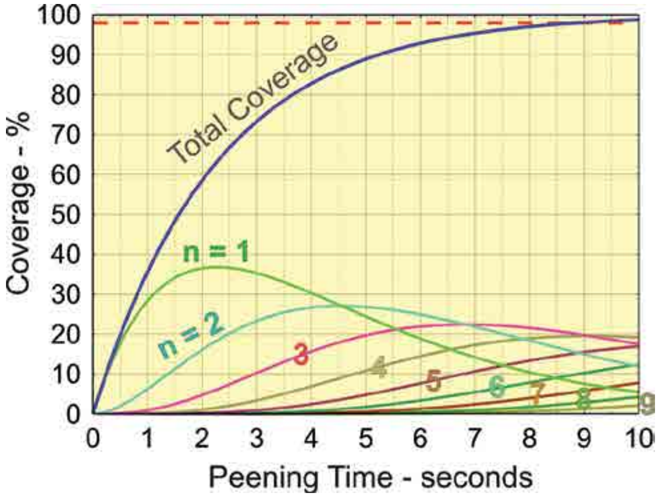

Fig.7. Multiple overlapping of dents.

Where **C** is the percentage coverage, **D** is the average diameter of each dent, **R** is the rate of impacting (number of dents imparted per unit area of surface per unit of peening time) and **t** is the peening time.

Q10: "How is coverage measured?"

A10: "The simplest method is to compare an image of the surface with standard reference images. One standard chart is shown as fig.8. There is, however, a subjective element in this procedure. On the other hand, the human brain can act as a marvellous computer—sometimes.

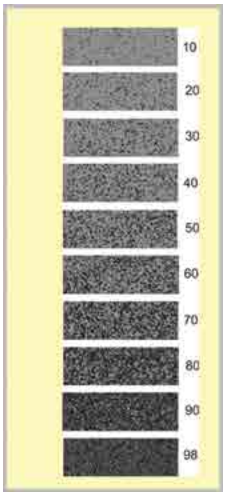

Fig.8. Standard comparison chart.

Coverage estimates based on actual measurements are usually based on linear intercepts. This principle is illustrated by fig.9. Just four short lines are shown though in practice many more longer lines would be analyzed. This to minimize statistical variability. Line four, for example, intersects dents much less than does line three. The length of each line would be taken to be 100% coverage if it only passed through dents. Line one represents measuring three dented areas.

Lineal analysis is very tedious if carried out manually. Computer-based image analysis is now available that is dedicated to coverage measurement. This involves far more lines and dent intercepts than can be employed manually."

Q11: "Which gives more fatigue life improvement—work hardening or compressive surface residual stress?"

A11: "First let us consider another factor that affects the fatigue life of components. For most components the

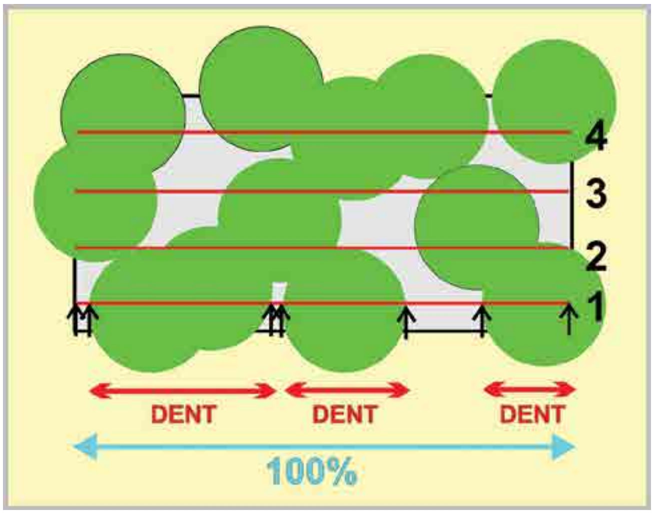

Fig.9. Principle of lineal analysis.

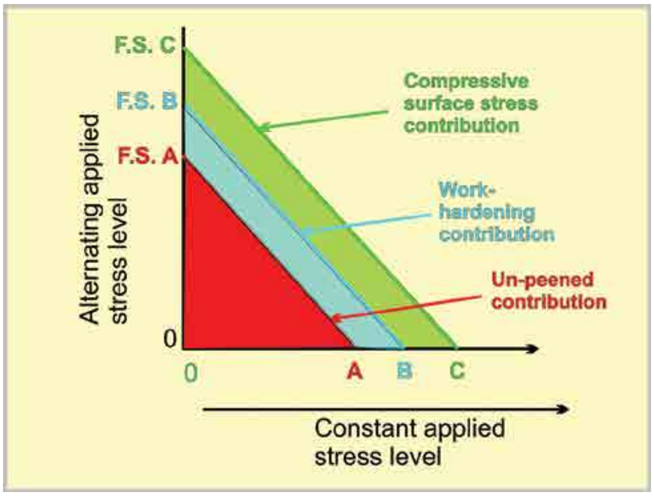

Fig.10. Contributions of shot peening to fatigue strength.

applied alternating stress does not vary by equal amounts above and below zero. A simple example is that of the leaf springs supporting a railway wagon. When stationary, the weight of the wagon applies a constant applied stress to the springs. The heavier the wagon the greater is this constant applied stress. If the constant applied stress were to reach the fracture strength of the springs they would simply break, so that no alternating stress could be applied. This, for unpeened springs, corresponds to point A in fig.10. Peened springs would not break until a constant applied level was greater—point C in fig.10. Work-hardening and compressive surface residual stress both contribute similar amounts to the increased fracture strength.

At lower constant applied stress levels alternating applied stresses can be applied. The lower the constant applied stress level the higher will be the alternating stress that can be applied before fatigue failure occurs. For zero constant applied stress the fatigue strength for unpeened springs is indicated as point **F.S. A** in fig.10. The work-hardening and surface compressive surface residual stress combine to raise the fatigue strength to level to point **F.S. C.** Their contributions to fatigue strength are similar for all constant applied stress levels."

Q12: "What controls are used to optimize shot peening?"
A12: "Customers normally specify the type and size of shot, percentage coverage and what is termed the "Peening Intensity" that should be applied to their components. These are specified based on previous experience. The percentage coverage is controlled by the time that a given shot stream is sprayed onto the component. "Peening Intensity—sometimes called "Almen Intensity"—is a control technique that has become essential for shot peeners.

Thin rectangular steel strips are shot peened on one major surface for different amounts of time. Shot peening plastically stretches the peened surface and generates a surface layer that contains compressive residual stress. These two factors combine to cause bending of the strip. This is illustrated by fig.11. Peened strips develop a curvature, **R**. If a given stream's average shot velocity is constant, the amount of bending will increase with increased peening time.

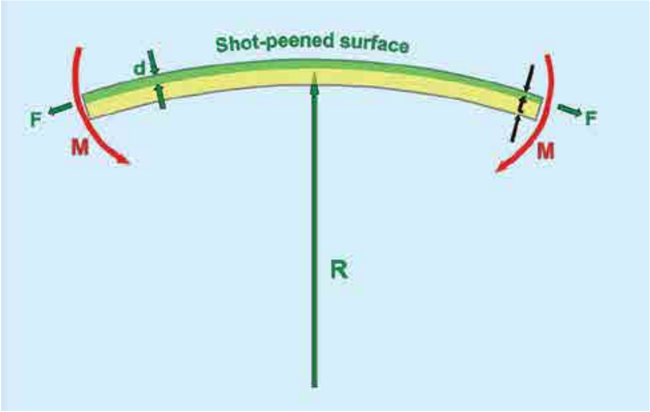

Fig.11. Bending of Almen strip caused by shot peening.

The amount of bending is determined by the "Arc Height" which is the deviation from flatness measured using a calibrated Almen Gauge. Arc heights increase with peening time. Nowadays we use a computer program to discover the curve that is the best fit to the set of measured points. One such curve is shown as fig.12. Note that the curve does not quite flatten out.

Fig.12 also indicates the universally accepted criterion for "Peening Intensity". Peening intensity is an arc height, **H**, that increases by precisely 10% when the peening time is doubled from **T** to **2T**.

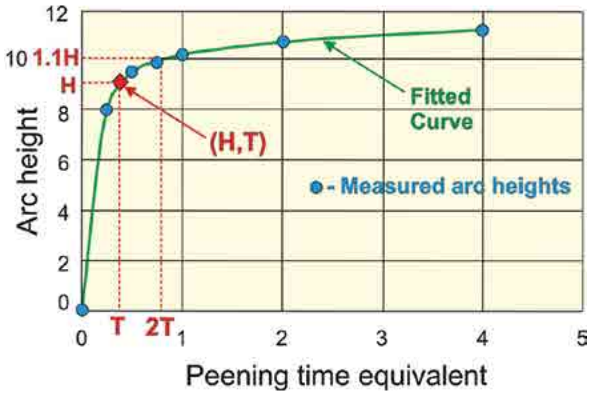

Fig.12. Arc height variation with shot peening time.

There are three different standard thicknesses of Almen strips. This permits sensitive arc heights to be developed over a wide range of peening intensities. The three thicknesses are labelled **N**, **A** and **C** with **N** being the thinnest and **C** being the thickest.

Everything about measuring peening intensity is rigorously controlled in order ensure that different organizations derive very similar values for a given shot stream. Fig.13 shows the basic principle of arc height measurement. An accurate dial gauge presses lightly on the Almen strip having been previously zeroed using a standard metal block. The strip itself is held lightly by magnetic forces generated in the four support balls.

Fig.13. Almen gauge.

DISCUSSION

A range of typical questions has been presented but it is by no means comprehensive. Some questions that have been fielded were posed by students, some by casual acquaintances. One important consideration is that enlightening questioners must be in the form of short replies. There is a strict limit on the information that can be absorbed in a matter of minutes. Technical articles concentrating on one specific topic can take hours, even weeks, to fully absorb. Illustrative figures for aiding answers to questions can be kept on either a smartphone or a laptop, or both.

ITAMCO Revolutionizes Gear Manufacturing at THRIVE Energy Conference

The recent THRIVE Energy Conference in February, 2024 served as a prime platform for ITAMCO (Indiana Technology and Manufacturing Companies) to unveil its ground-breaking advancements in gear manufacturing technology. Amidst discussions on energy innovation and sustainability, ITAMCO seized the opportunity to showcase its key innovations that are reshaping the landscape of gear production.

At the heart of ITAMCO's presentation was its cutting-edge use of machine learning (ML) and advanced analytics in gear manufacturing processes. By harnessing ML algorithms, ITAMCO has pioneered energy efficient solutions specifically tailored for gear systems. These solutions enable lower energy consumption of the gear manufacturing process.

Moreover, ITAMCO spotlighted its IoT-enabled gear monitoring systems which provide real-time insights into gear performance and health. Through continuous monitoring and data analytics, organizations can optimize gear operation, prevent unexpected failures, and maximize energy efficiency across various applications.

In addition to its technological advancements, ITAMCO emphasized its commitment to sustainability in gear manufacturing. ITAMCO ensures transparency and traceability in the supply chain, promoting responsible sourcing of materials and ethical manufacturing practices made in the USA. This not only aligns with the growing demand for sustainable solutions but also reinforces ITAMCO's dedication to environmental stewardship.

By participating in the THRIVE Energy Conference, ITAMCO demonstrated its leadership in revolutionizing gear manufacturing through innovation and sustainability. Through collaboration with industry peers and stakeholders, ITAMCO continues to drive positive change and shape the future of energy by delivering reliable, efficient, and environmentally conscious gear solutions.

In conclusion, ITAMCO's participation in the THRIVE Energy Conference underscored its commitment to advancing gear manufacturing technology while promoting sustainability in the energy sector. Through its pioneering innovations, ITAMCO is poised to lead the industry towards a more resilient and sustainable energy future.

About ITAMCO

ITAMCO has been recognized as one of the premier advanced manufacturing and technology firms in the United States. The company collaborates with like-minded professionals from the world's most respected companies and universities across the globe to solve complex challenges and deliver innovative solutions.