SHOT PEENING MEDIA
Its Effect on Process Consistency and Resultant Improvement in Fatigue Characteristics

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KEY WORDS

Size, Shape, Hardness, Density, Durability, Material, Image Analysis, XPS, Media, Fatigue

INTRODUCTION

The shot peening process is most often used to improve fatigue properties of metal parts. In order to achieve optimum, repeatable and reliable fatigue enhancement from the shot peening process, the important shot peening parameters must be controlled. The single most critical parameter of the shot peening process is the shot itself. Without the correct quality media, all other peening parameters are extraneous and the desired fatigue improvement and consistency of improvement will not be achieved. It is surprising how little attention is paid, particularly during processing, to this most critical parameter. Control of peening media, both in media selection and with in-process controls, is possibly the easiest way to increase amount and consistency of fatigue improvement by shot peening.

There are six characteristics of shot peening media that are important: size, shape, hardness, density, durability and material.

SIZE

Media size is the most frequently measured and evaluated media characteristic. Much data has been generated in the past showing that the relationship between shot size and peening intensity (1, 2). As shot size increases, particle mass increases and peening intensity will also increase provided that particle velocity remains the same or greater.

Traditionally, media size has been evaluated using sieve analysis. In sieve analysis, a series of four or five sieves are stacked according to their opening size (the largest on top to the smallest on the bottom). Media is poured onto the top sieve and the sieve stack is placed in a shaking device for a specified period of time. The amount of media (weight) remaining on each sieve after shaking is measured, recorded and compared with applicable specifications. An example of sieve analysis of two different media is found in Table 1.

Specification	Cut Wire 0.9 mm	Cast S-330	Sieve Size
Maximum 2% on	0%	0%	16 mesh
Maximum 50 % on	1.2%	17.2%	18 mesh
Cum. Min. 90% on	99.0%	94.7%	20 mesh
Cum. Min. 98% on	100.0%	99.8%	25 mesh

Table 1. SIEVE ANALYSIS - per MIL-S-13165C

Recently, Image Analysis (IA) has been used to evaluate media size and shape (3). In IA, a layer of shot is projected on a computer monitor using a video camera. The computer then measures the size and shape of each individual particle viewed. Many particles can be included in a single field of view and as many fields as desired can be processed. It is possible to evaluate thousands of particles in a short period of time. Measurements such as random diameter (for shot size) and particle roundness (for shot shape) are collected and input into computer software programs. These software programs are able to produce output data in a variety of formats such as statistical terms (mean, standard deviation, histograms, range, maximum, minimum,etc.) or Statistical Process Control terms (Proces Control Charts, Distribution Analysis, Process Capability Studies, Percentage over or under specified limits). A brief example of statistical output available from Image Analysis is presented in Table 2.

(inches)	Cut Wire 0.9 mm	Cast S-330	Ratio
Mean	0.0433	0.0403	1 : 0.93
Standard Deviation	0.0018	0.0062	1 : 3.44
Range	0.0107	0.0407	1 : 3.80

Table 2. IMAGE ANALYSIS - Minimum 1250 pieces

While sieve analysis produces a general idea of the size of shot peening media, IA provides much more descriptive data that can more clearly define the physical characteristics of peening media. The more descriptive output data possible with IA gives the user much better knowledge of the actual size and consistency of the media evaluated. For example, analysis of data in Table 1 would lead one to conclude that the two media were very similar in size (CS 330 shot being slightly larger due to 17.2%

on the 18 mesh sieve versus 1.2% for CW 35). Both media are well within the specified limits. Table 2, in which the very same samples were measured for size by IA, clearly shows that the conditioned cut wire media (CW 35) is larger on average and much more consistent than the cast steel media (CS 330).

Table 3 is a comparison of peening intensities generated by the two media in Tables 1 and 2. All peening parameters were identical; only the media was changed. Twenty-five Almen A strips were peened at the saturation time for each media. Prior to peening, each Almen A strip was selected for flatness +/-0.0005 inches. The statistics in Table 3 show that the slightly larger and more consistent media CW 35 produced somewhat higher and more consistent intensity values which agrees with the size evaluation done by IA in Table 2.

(0.001 inches)	Cut Wire 0.9 mm	Cast S-330	Ratio
Mean	22.18	21.37	1 : 0.96
Standard Deviation	0.724	1.223	1 : 1.69
Range	2.3	4.3	1 : 1.87

Table 3. PEENING INTENSITY - A Strip

Wantanabe (4) and Chevrolet (5) both observed more consistent fatigue life on automotive gears and suspension springs with conditioned cut wire media as compared with cast steel media of similar size and hardness. There is no doubt that sharp edge broken particles can be detrimental to Fatigue Resistance.

SHAPE

The second most frequently measured media characteristic is shape. It is important that shot peening media be spherical in shape and free from potentially damaging sharp edges. Figure 1 clearly shows surface damage (cut and tears) which was caused by sharp edge broken particles. Simpson (6) plotted the influence of broken particles on Fatigue Life. As percentage of broken particles increases; Fatigue Life decreases. Chevrolet (5) and recent data (Table 4) found that the media with lower amount of broken particles gave more consistent and

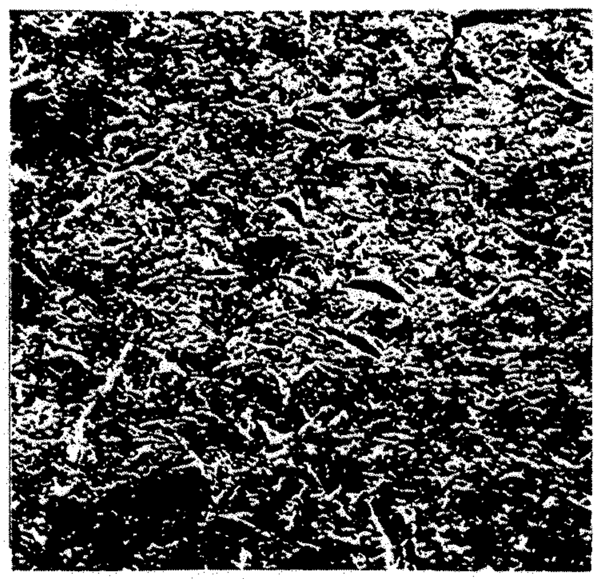

Figure 1 - SURFACE DAMAGE

higher average Fatigue Life than media with

higher broken particle count. Wantanabe (4) concluded that increased amount of broken particles gradually decreases the fatigue benefit that can be achieved with shot peening.

	Cast Steel Shot	Carbon Cut Wire
Sample 1	5.36	12.62
Sample 2	9.06	16.32
Sample 3	14.98	17.16
Sample 4	16.50	19.61
Sample 5	16.72	20.09
Sample 6	18.37	22.28
Average Life	13.50	18.01
Standard Deviation	5.12	3.40

Table 4. FATIGUE RESULTS - Carburized Gear Life (hours)

Almost all shot peening specifications attempt to control and minimize the amount of potentially damaging particles. The traditional method for evaluation of peening media shape is visual evaluation using a ten power (10x) or twenty power (20x) magnifier. New technology for evaluation of media shape is available with Image Analysis (IA). At the same time IA performs measurement of particle size, it can also measure particle roundness, or shape. Particle roundness, or Shape Factor, can be measured using a well-known physics formula:

$$\text{Shape Factor} = (4 \times \pi \times A) / P^2.$$

A is the area of the particle and P is its perimeter. The Shape Factor (roundness) for a circle would be 1.000 and, for a line, the Shape Factor is 0.

Figure 2 shows frequently used sketches of acceptable and unacceptable particle shape and the respective roundness (shape) measurements for each particle. Acceptable shapes have a value of 0.858 or higher where unacceptable shapes were 0.821 and lower. As with size measurement, the shape of any number

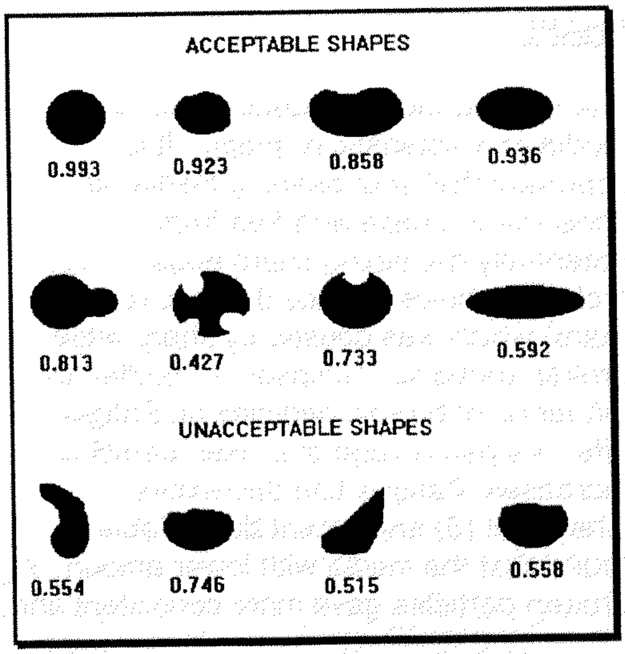

Figure 2 - SHAPE FACTOR

of particles can be measured. Output of the

IA system is more detailed and descriptive than results obtained with the traditional method of visual evaluation. With an automated inspection system, evaluation of media shape can be much more precise and accurate (3). This is particularly true with shape evaluation since an automated system such as IA removes the possibility of human error and subjectivity that are very common with the visual inspection.

Using current technology, it is possible to mount an IA system on a shot peening machine and measure the size and shape of the media in real time as the machine is running.

HARDNESS

Media hardness is a well-known characteristic. In all four previous International Conferences on Shot Peening, the influence of media hardness was discussed. It is always recommended that, for optimum compressive residual stress (magnitude and depth), media should be at least as hard as the part being peened. This is particularly true when peening parts above hardness HV 450, which is the center of the normal hardness range (HV 390 - 510) of cast steel shot. For parts above HV 450 in hardness, a harder media should be used.

But what about the Almen Strip? The standard specified hardness of Almen strips is HV 430 - 510 with an average of HV 470. Arnaud (7) clearly showed that peening with media at hardness HV 440 gave much lower arc heights and saturation points than higher hardness media (e.g., 640 HV that is a standard hardness for cut wire shot). In fact, Arnaud's data indicates that Almen strip arc heights will increase with increasing media hardness.

It is this author's recommendation that, for optimum process control, media hardness should be as consistent as possible and a minimum of HV 510 - the maximum hardness for Almen strips.

DENSITY

Density is a characteristic of peening shot that is included in most media specifications, but is rarely measured by the user. In fact many users do not know how to measure density of their media. A density measurement can be a quick and valuable indication of the presence of large amounts of voids, porosity or other internal defects in shot particles. Particles with significant internal defects will have low density and tend to shatter and breakdown much faster than solid sound particles thus reducing average particle size and increasing the amount of unacceptable sharp edge broken pieces.

Another importance of density has to do with potential Kinetic Energy of a particle of shot. Kinetic Energy (KE) of a moving object is a product the mass of the object and its velocity. Mass of a particle is the product of its density and volume (8). As particle density increases, particle mass also increases. Therefore, the media with the highest density will have the highest Kinetic Energy at equivalent velocities.

Gillespie (8) ranked peening media in order of density as well as durability - Useful Life and Resistance to Fracture (RTF). The media with the highest density (carbon steel cut wire shot) also had the best Useful Life and RTF. Cast steel shot, ceramic and glass beads exhibited Useful Life and RTF that ranked in the same order as their density (cast steel followed by ceramic and then by glass). Stainless steel cut wire shot has a density slightly higher than carbon steel cut wire shot and its durability is also measurably higher than the carbon steel cut wire shot as shown in the next section on DURABILITY.

Media with the highest and most consistent density should produce the highest and most consistent peening intensities with the lowest potential for surface damage.

DURABILITY

Durability of shot peening media is one of its most important and complex characteristics. It can be defined as the ability of shot peening media to maintain its size and shape during use. Media size breaks down by becoming smaller. Useful Life (UL) of peening media is how long, or how many cycles, media can endure before becoming unacceptable in size. Media shape deteriorates by forming sharp edge broken pieces. Resistance to Fracture (RTF) is how long media can resist fracturing or breaking.

Media durability influences Fatigue Resistance of parts peened, environmental concerns (dust generation and disposal), equipment maintenance and media costs.

The effect of potentially damaging sharp edge particles has been discussed in the SHAPE section above. The importance of size consistency on Fatigue Resistance has been demonstrated in the SIZE section.

Table 5 shows the results of measurements of dust generated by three media - Stainless Steel Conditioned Cut Wire, Carbon Steel Conditioned Cut Wire and Carbon Cast Steel - of similar size and Hardness. Also indicated in Table 5 is the Useful Life data for the three media. It is not surprising that the media with the best Useful Life (Stainless Conditioned Cut Wire) has the lowest dust generation rate. The media exhibiting the lowest Useful Life has the highest dust generation rate. It is clear that the more durable the peening media; the lower the amount of dust generated by media breakdown.

	Rate (grams/cycle)	Useful Life (cycles)
Stainless Cut Wire	0.0042	11,124
Carbon Cut Wire	0.0147	3,327
Carbon Cast Steel	0.0254	362

Table 5. DUST GENERATION RATE - Steel Media

Obviously, media that breaks into sharp edge abrasive particles will cause more wear on the peening machine and associated tooling than media that resists fracture and does not form broken pieces. Gillespie (8) compared the Useful Life of peening media and their Resistance to Fracture. In every case, the media with the highest Useful Life was also the media with the highest Resistance to Fracture.

In order to properly evaluate cost of media consumed in the shot peening process, one must consider the durability of the media as well as its initial cost. Table 6 is a cost comparison of three media based on their initial cost and their durability. The lower the media Breakdown Rate, the better its durability (Useful Life). In Table 6, the media with the lowest cost per cycle (Stainless Conditioned Cut Wire) was the media with the highest initial cost. This was due to its much better durability (Lower Breakdown Rate).

Media	Price (cents/gram)	Breakdown Rate (grams/cycle)	Cost per Cycle (cents)	Useful Life (cycles)
Stainless Cut Wire	1.588	0.009	0.0143	11,127
Carbon Cut Wire	0.544	0.030	0.0163	3,327
Carbon Cast Steel	0.165	0.276	0.0455	362

Table 6. COST COMPARISON - Steel Media

MATERIAL

The final characteristic that should be discussed is the material. There are a number of different materials from which to make shot peening shot. Glass beads, Ceramic beads, Cast Carbon Steel shot, Carbon Steel Conditioned Cut Wire shot and Stainless Steel Conditioned Cut Wire shot are the most commonly used media when peening for improved Fatigue Resistance. Glass beads, Ceramic beads and Stainless Steel shot are normally used to avoid Iron contamination of non-ferrous metal parts. Premier Shot Company performed a test program to measure differences in Iron residue left by the three steel media.

Samples panels made of Aluminum alloy 7075 (frequently used in the manufacture of aircraft) sheet were peened with new media of the same size and hardness - 0.35 mm diameter and HV 600-700. X-ray Photoelectron Spectroscopy (XPS) was used to analyze the surface of the panels peened with the three media (cast carbon steel, carbon steel conditioned cut wire and stainless steel (Type 302) conditioned cut wire shot). XPS analysis was also performed on unpeened panels for comparison purposes.

In the XPS process, the surface of the material is irradiated with X-Rays that interact only with surface atoms. Electrons of various energies are emitted. The energy levels of the electrons identify the atoms from which the electrons were emitted. The Atomic Concentration of the elements present can then be calculated using a computer model.

Figure 3 summarizes the Iron residue measured in the four conditions. The unpeened sample showed a small amount of Iron (0.55%) which is normally present in the 7075 alloy. Stainless steel media left a residue of Iron (2.06%) which was in combination with Nickel and Chromium typical of the Type 302 alloy and not subject to formation of Iron Oxide (rust). Carbon steel cut wire shot left a residue of Iron (3.34%) which was in combination with Oxygen as Iron Oxide. Cast steel shot left the highest amount of Iron residue (30.91%) which was also in combination with Oxygen as Iron Oxide.

To avoid possible pitting or corrosion problems, many shot peening specifications require that Aluminum, or nonferrous, alloys be decontaminated after shot peening with carbon steel shot. The amount of decontamination necessary will, of course, be dependent on the residue left on the surface of the part.

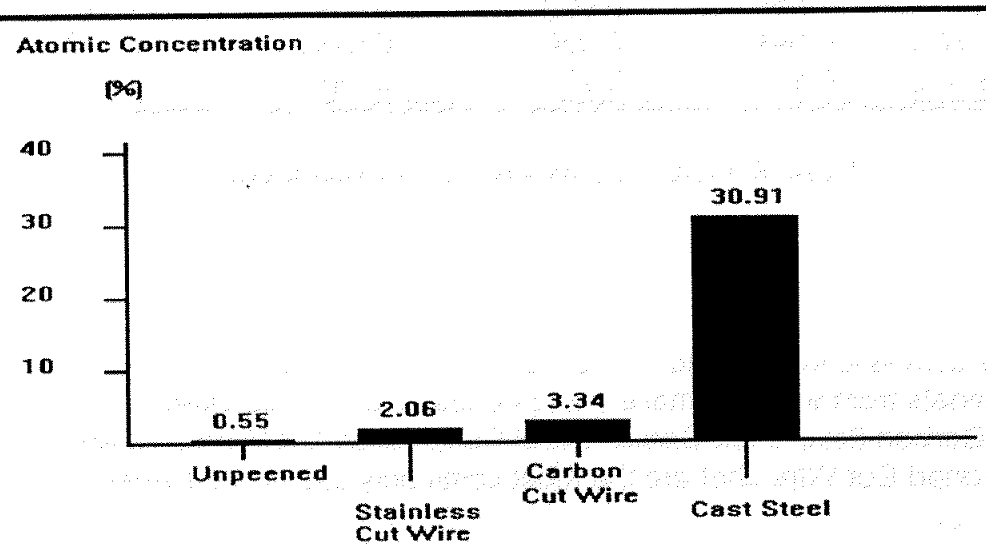

Figure 3 - XPS RESULTS

Durability and initial cost are other major factors in the selection of the material of the peening media. Both of these factors were discussed in the previous section on Durability.

CONCLUSIONS

For optimum improvement in Fatigue Resistance using shot peening, the following conclusions can be drawn regarding peening media:

1) Size - Use media with the most consistent size distribution,
2) Shape - Select media that resists fracture and formation of sharp edge particles,
3) Hardness - Peen with media at least as hard as the part to be peened and as hard as Almen Strips,
4) Density - Media with the highest density are the most durable and fracture resistant,
5) Durability - Select media exhibiting the best Useful Life and Resistance to Fracture,
6) Material - Choose media with the best durability and that leave the lowest amount of surface residue.

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