Effective Use of Cast Steel Shot for Shot Peening

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The formula for Kinetic Energy (1/2 MV^2) says much that shot peen operators need to know about how the impact-power of cast steel shot is generated—but, it doesn't say all that needs to be said, and done, to achieve optimum shot peening results. A good basic understanding of the characteristics of cast steel shot, its selection, and the physical changes it undergoes while performing its peening function, are essential for a cost efficient shot peening operation. Equally important is a good basic understanding of the several functions performed by shot peening equipment, and how component wear affects peening productivity and operating costs.

Shot peening is a cold-working impact process in which the workpiece is subjected to successive bombardment by a high velocity blast stream containing many millions of hardened, closely-sized, cast steel pellets, each acting as a miniballpeen hammer, in order to achieve these results:

- Increase fatigue-life of metal parts
- Prevent incidence/propagation of stress corrosion cracks
- Correct metal porosity problems
- Peen-form metal parts

Most shot-peening applications are related to the automotive and aerospace industries, where increasing fatigue life of parts has the highest priority. Shot peening has increased fatigue life of metal parts as much as one hundred-fold, or more!

How Shot-Peening Works

The key to increasing fatigue life, and preventing stress corrosion cracking, is for the steel shot to be used in a manner that produces at the surface of the workpiece, a uniform depth layer of compressive stress. The powerful impact-force of the individual steel pellets, with all their energy expended on an extremely small area of contact, produces indentations which create the layer of compressive stress.

Properly operated, not only will the shot peening process be effective in satisfying the users' quality needs and goals, but will also assure optimum productivity and the lowest possible operating costs.

Steel Shot Manufacture

Selected steel scrap and alloys are melted in electric furnaces. The 3000F molten steel is divided into small streams that are poured onto powerful water jets, disintegrating the molten metal into random-sized droplets which fall into a quench pit. The resultant shot is dried, fully hardened by heat treatment and quench, then tempered to the required hardness range for specific peening applications.

Impact Energy: Its Source

The impact power of cast steel shot is governed by the mass and velocity of the individual pellets. Implicit in the equation for kinetic energy is the fact that, for a given mass (the steel pellet), the impact-power delivered to the work varies as the square of a change in velocity.

Not as implicit is the fact that the mass, or weight, of a shot pellet varies as the cube of a change in diameter. A seemingly slight change in shot diameter can have drastic effect on its impact-power!

Velocity is derived from either airless blast equipment where the shot is hurled by centrifugal force from a bladed wheel (Fig. 1), or by air-blast equipment in which the shot is metered into a compressed air stream via hoses and is propelled through the blast-nozzle orifice. Velocity in centrifugal blast units is governed by the wheel diameter and its RPM. Standard blast-wheels (19-1/2" diameter, 2250 RPM) develop abrasive velocity of approximately 245 FPS. Years of field experience have shown this velocity to be effective for most wheel-blast shot peening applications. Variable speed wheels are also used in peening, primarily where different parts to be peened require different intensities. With variabled speed wheels, one size shot can be used to peen a variety of parts in the same machine, simply by changing wheel RPM to attain the required intensities.

In all cases, though, once the shot size/velocity combination has been established for a required intensity, the velocity can be considered as "locked in." Thus, the impact-force being delivered will change only if the mass factor (shot sizing in the work-mix) is altered.

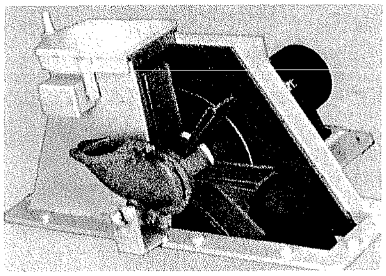


Fig. 1. A bladed wheel hurls the steel shot in centrifugal blast equipment.

Peening Equipment - Additional Features

In addition to providing velocity, the peening equipment is designed to recirculate proper size shot recovered from the separator system, and deliver to the propelling device (nozzle or blast-wheel) a controlled number of pounds of media per minute during the blast-cycle. Peening productivity depends on the flow being at the established rate. Centrifugal peening equipment, used in high volume peening production applications, can have wheel flow rates as high as 2000 pounds per minute, and at the low end, about 350 pounds.

Finally, the blast stream must be so directed at the workpiece that the angle of impact is most effective. The peening system is designed to provide proper aim.

Ideally...

For a given peening application, there is a given size and hardness of cast steel shot, propelled at a given velocity, with the blast stream at a given flow rate, impacting the work-piece at a given angle of incidence, that will assure effective and consistent peening results, optimum productivity, and the lowest costs.

That's ideally, but the chance of all those "givens" holding true is slight—**unless a rigid, disciplined program of preventive control measures, as will be described, is adopted and practiced routinely.**

Once new shot is put in motion (at the specified velocity and flow rate) two entirely different forces of attrition come into play, one attacking the shot via impact abuse, the other attacking wheel components, via wear abuse.

Shot Size in the System

Selection of shot size to be purchased requires great study and care by the contractor, or, for in-house applications, by the Engineering Department. Once that decision is made, though, an even greater challenge comes into play: Controlling size distribution of the shot in the work-mix. The as-purchased shot was specified because it was considered the size best capable of producing the required depth layer of compressive stress. Question: How different is the size of shot in the work-mix?

Peening Media Breakdown

It is inevitable: The same powerful energy-force delivered by the cast steel shot when impacting against the work-piece to produce that layer of compressive stress, inevitably takes its toil on the shot pellet itself. The steel shot, constantly recycling through the system, absorbs many hundreds of punishing impacts before finally succumbing. The first effect of the impact punishment is to work harden the surface of the steel pellet, leading to a flaking/spalling action.

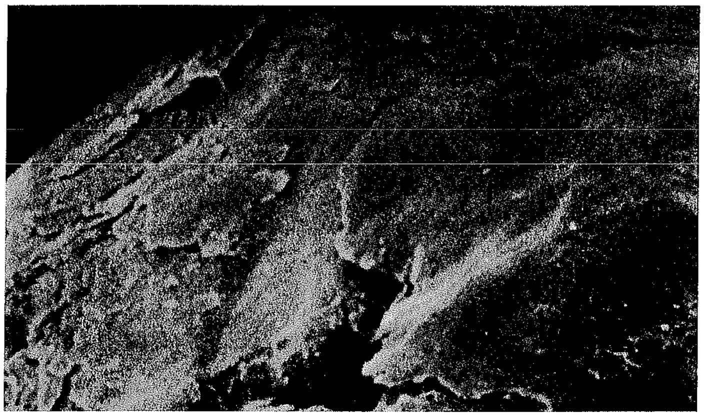


Fig. 2. FlakinglSpalling of Steel Shot

This "onion-peel" effect can cause cast steel shot to lose enough diameter to become one or two sizes smaller—before fracture will occur. During the flaking/spalling phase, severe internal damage is inflicted on the pellets, evidenced by voids and ruptures, which ultimately work their way to the surface and cause fracture-failure. Fractured particles, upon further repeated impacts, are forged into smaller diameter spheres which ultimately re-fracture into even smaller particles. It is this combination of events that transforms the as-purchased new cast steel shot into a work-mix, which undergoes constant size distribution change as undersize flaked/spalled pellets and shot fractures are generated and then extracted by the separator and dust collector system and replaced with new shot.

A Quick Perspective

Remembering that the weight or mass of a sphere varies as the cube of its diameter, let us consider the effect of diameter change of a steel pellet from:

.0469" to .0394"

The .0394" pellet is still round —it is not "broken"— and at 84% of the diameter of the .0469" pellet, it's not easy to see the difference. To most operators, it probably would get this response: "Looks O.K., no problem."

But the downsized .0394" shot has only a little than half (59%) the weight, or impact-power of .0469" shot!

Loud and clear, the message is: Don't send a boy to do a man's job!

Decreasing shot diameter from .0469" to .0394" is the equivalent of flaking/spalling down to the next smaller shot size, i.e, whether #660 to #550, or #280 to #230, etc. The result is the same—the impact-power decreases to almost half that of the original size shot. (One exception: #110 - the loss in impact-power would be even more.)

Perspective: The .0469" pellet needs to lose only four-thousandths inch in radius (the thickness of one sheet of computer printer paper) to flake-spall down to .0394". Smaller sizes need to lose only two-thousandths inch or less in radius to shrink down one size.

More Perspective

The effect of flaking/spalling shot diameter down two sizes:

. 0469" to .0331"

The .0331" pellet is 70% the diameter of the .0469" pellet, **but has only 35% the mass, or about one-third the impact-power!** This effect of shrinking two sizes applies to any given shot size, except #110, which would lose much more impact power.

Depending on size and hardness, steel shot can downsize by flaking-spalling as much as two full sizes before fracture occurs. Work-mix samples taken from peening operations confirm this.

The Obvious Message

When a work-mix pellet of steel shot has only one-half or one-third the mass or impact-power of its original size, it can no longer produce the specified depth layer of compressive stress. It does not belong in the work-mix regardless of whether it lost its impact power by flaking/spalling or by fracture-failure.

Increasing velocity to offset size distribution imbalance makes the problem worse, as greater velocity sharply increases the rate of shot attrition, thus generating even more of the already excessive undersize media. In addition, since the impact-power will increase as the square of the increase in velocity, any full-size shot in the work-mix will have excess intensity, and can damage the work.

Almen Intensity Strips

Use of Almen intensity strips as a control measure of the repeatability and reliability of the peening process is based on the assumption that if the shot in the blast stream impacting on the work-piece is producing the required depth layer of compressive stress, then the Almen strip arc height reading from a test taken at the same time, under the same conditions, can serve as a reliable control-measure.

If, however, when testing for the Almen strip intensity, it is found that the supposedly "locked in" factors of shot size and velocity produce an intensity reading lower than required, or that additional blast-time is needed to achieve the target intensity, it is a clear signal that there has been a change in one or both factors. By far, the most common problem is that there has been a change in work-mix size-distribution. **Excess undersize shot is in the blast stream!**

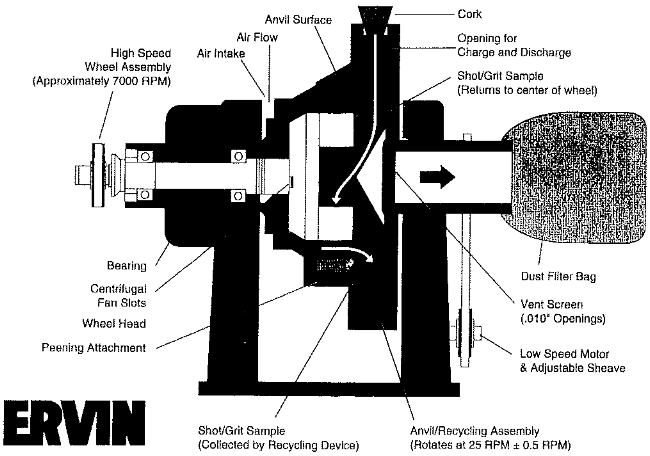


Fig.3 Ervin Shot Tester

Shot Size vs. Arc Height

To demonstrate the effect of shot size variation on Almen strip arc heights, comparisons were made in the Ervin Shot Tester, adapted for Almen strip tests. (See Fig. 3 above)
Shot sizes tested: #390 & #170 Shot and a 50/50 mix of #390 and #170. Target arc height: 18.0 to 22.0 Almen A.
Test results—arc height readings: #390 = 18.8 arc height in 20 passes and 21.7 in 40 passes;
#170 = 8.4 in 20 passes, and 8.7 in 40 passes;
50/50 Mix #390 & #170—19.5 in 40 passes.

Observation

The #170 could be run forever and could never attain the #390 target arc height. At less than 50% the diameter of #390, and less than 10% the mass, the #170 simply did not have sufficient impact-power. The mix of 50/50 #390 and #170 attained the target arc height, but required double the passes (40).

Another Observation

Given that the 50% #170 could never attain target arc height, it is obvious that it was only the 50% #390 that did the work, and, at 50% of the load, it most naturally would take twice as long. (A test comparing a 50/50 mix of #390 #280 also took the mix twice as long to reach target arc height, as only the 50% #390 was doing the job!

(Note: With respect to "Coverage", the #170 and #280 have a higher pellet count than the #390. However, while the smaller shot would provide great coverage, it would be false coverage, as the smaller shot could not contribute to the arc height attained.)

The Message

Yes, a work-mix containing even a significant percentage of under-size media (two or more sizes smaller than the specified new shot) can produce the target intensity and the required depth layer of compressive stress, **but only at the high cost of low productivity**.

The consumption cost of cast steel peening shot should not exceed 25% to 30% of the total cost to peen. Production labor, maintenance labor and parts, power, and overhead costs make up the other 70% to 75%. Dividing these remaining costs by half the throughput that should be attained results in out-of-sight cost per unit of work peened!

Work-Mix Size Distribution - What Should It Be?

Because, as demonstrated by the "Quick Perspective" examples, plus the results of the Ervin Shot Tester studies, work-mix shot one, two, or more, sizes smaller than the original specified shot simply does not have sufficient impact-power to produce the required Almen intensity, there can be no valid reason for their presence in the peening system.

Looking strictly at shot consumed per wheel hour, is misleading, as the shot cost "saved" by retaining non-productive fines can be four or five times over due to dividing all the other costs by reduced throughput, i.e, calculating total costs on a per unpeened basis, rather than per wheel hour shot cost only.

Inefficiencies of the separating systems have to be recognized. Asking an air-wash separator to distinguish between pellets of .0469" and .0394" diameters (.0394" only 16% smaller) may seem too challenging, but comparing costs, the .0394" pellet has only 59% as much mass, or 41% less weight, which should be less challenging. Screen classifiers are an option to augment the air-wash system. By observing proper operating practice, 80% efficiency should be attainable. Thus, a work-mix should contain a minimum of 80% media equivalent to the new shot size.

Peening vs. Blast cleaning

Distinction should be made between peening operations where the primary purpose is to improve product life via a controlled, uniform depth layer of compressive stress, and those operations where removal of surface contaminants via blast cleaning is the primary purpose, and where some beneficial peening results may be realized as a side-effect (ferrous and non-ferrous castings, for example). For blast cleaning work-mixes to be effective, both large and small media is necessary, with the finess scouring rust and oxide scale, etc., from minute pits and fissures in the metal surface. Such a work-mix is the very last thing a true peening shop should have, if its aim is to be both effective and cost efficient!

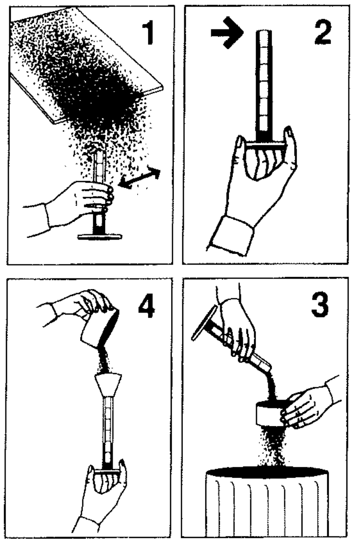
Controlling the Work-mix

(1) Add new abrasive every operating shift.
(2) Maintain feed hopper at or above 3/4 level at all times.
(3) Do not allow abrasive spillage or leakage to accumulate; return to system daily.
(4) inspect the shot curtain flowing over the air-wash shed plate daily to be sure it is even.
(5) Check work-mix size distribution daily. Recommended: Use the Ervin Spotcheck Gauge (Fig. 4 and Fig. 5 on next page) which requires less than five minutes to use, and provides instant feedback.

Insufficient Abrasive Flow

Ammeter: This sensitive device registers the amperage load on the motor driving the blast-wheel. It is the only practical way of determining how much abrasive is thrown by the wheel during the blast-cycle. Peak efficiency from the peening equipment is attained only when the wheel throws the rated maximum quantity of abrasive. (See Fig. 6 on next page.)

When blast-cycle time is based on the rated maximum flow, but the ammeter shows less than full load amps (Fig. 7),



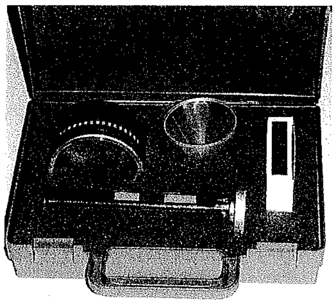


Fig. 4 and 5. Ervin Spot-check Gauge

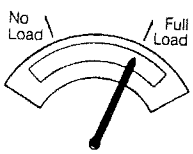


Fig. 6. The ammeter at full load

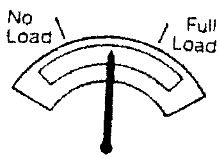


Fig. 7. Low ammeter reading

approximately thirty (30) pounds of shot per amp below full load is **not** being thrown. Shot not thrown can't peen!

To Prevent Low Amps

(1) Calibrate all ammeters on a regular basis; be sure to keep them in good working order.
(2) Post full-load amp reading above the ammeter and make sure it is clearly visible at all times.
(3) Shot to be added each operating shift. Maintain feed hopper at least 3/4 full, always.
(4) Inspect impeller wear daily. When leading edges are worn more than 1/8", change impellers (Excess wear of the impeller causes it to lose its ability to keep up with the abrasive flow.)

The Blast Stream. Is It On Target?

Misdirection of the blast stream, with some abrasive missing the work, and impacting instead on equipment wear parts, results in these problems:

1. Spotty peening of work-piece
2. Excessive parts' wear
3. Excess machine downtime
4. Excess shot usage
5. Lower productivity due to need for extended blast time

As little as a 10% shift in blast pattern away from proper aim can translate into 25% loss in peening efficiency. What must be recognized is that the inevitable factor of wear and tear on blast-wheel components will eventually cause a shift in the location and concentration of the blast-pattern. Exceptional wear tolerance has been built into blast equipment, but when wear goes beyond that tolerance, components can no longer perform properly. The blast pattern strays from target, and the angle of shot impingement also changes, which in turn can affect intensity readings.

Consider a 40 HP wheel: Every minute, 1,000 pounds of abrasive passes through the impeller, out the control cage opening, to be hurled off the blades.

Effect of Componentry Wear

Impeller: When wear on the leading edge of the impeller segments exceeds 1/8", the abrasive will hit the back of the blade rather than being delivered to the throwing face. The hotspot and overall blast pattern becomes badly diffused.

Control Cage: When wear of the beveled edge exceeds 1/2" (in some cases only 1/4"), the blast pattern is lengthened, causing some abrasive to miss the work-piece, and changing the angle of impact.

Blades: When blades become deeply grooved, channeling of the shot occurs, and because it is not flowing across the full width of the blade, the blast pattern is distorted.

Tramp Metal: When wedged between the impeller and control cage, tramp metal can cause the cage and the blast pattern to shift.

Checking the Blast Pattern

Consider where the work-piece surface to be peened is in relation to the blast wheel. The object is to place and secure a sheet metal target-plate at the location of the work-piece, then, after blasting for 10, 20, or 30 seconds, check to see the area and location of the blast pattern. The hot-spot (hot to the touch, and usually about 3" x 10") should be located approximately 8" in advance of the centerline of the wheel. This is the area of concentrated, maximum intensity. **A weekly blast pattern check is a foolproof procedure that tells you, now, whether the blast pattern is on target.**

Shot Size Specifications - Cast Steel Peening Shot

Whether AMS (Aerospace) or SAE (Non-aerospace) size specifications are involved, common to both are the ASTM-E-11 test sieves, which are used by both shot peeners and shot producers to assure that the shot delivered to the user meets specifications. All AMS shot sizes are specified by a series of five consecutive ASTM sieves, nested as shown in the example below, for #390 shot. SAE specifications use four sieves instead of five, with different maximum percentages being assigned.

Sieve	AMS	SAE
.0661	All Pass	All Pass
.0555	2% Max on	5%
.0469	50% Max on	n/a
.0394	90% Cum. Min. on	85%
.0331	98% Cum. Min. on	96%

It would seem that relatively minor differences exist between the two specifications. The most important number is the percentage retained on the nominal sieve, .0394" in the above example, with the difference being 85% vs. 90%. For peening applications not governed by aerospace specifications, most shot peeners find they can use the SAE standard sizing for #230 and larger, thus avoiding the costly premium caused by the special screening process required to meet the AMS specifications. For sizes smaller than #230, AMS screening has five sizes (190, 170, 130, 110, and 70) vs. three SAE sizes, (170, 110, and 70).

Obviously, there are significant differences in the fine shot sizing that must be taken into account.

Fig. 8 AMS Steel Peening Shot

Shot Size	ASTM Nominal Sieve	Approx. Pellets Per lb
660	.0661"	14,000
550	.0555"	24,000
460	.0469"	40,000
390	.0394"	68,000
330	.0331"	114,000
280	.0278"	192,000
230	.0234"	324,000
190	.0197"	540,000
170	.0165"	914,000
130	.0139"	1,530,000
110	.0117"	2,500,000
--	.0098"	--
--	.0083"	--
70	.0070"	8,200,000

Fig. 9 SAE Steel Peening Shot

Shot Size	ASTM Nominal Sieve	Approx. Pellets Per lb
660	.0661"	14,000
550	.0555"	24,000
460	.0469"	40,000
390	.0394"	68,000
330	.0331"	114,000
280	.0278"	192,000
230	.0234"	324,000
--	.0197"	
170	.0165"	745,000
--	.0139"	
110	.0117"	2,100,000
	.0098"	
	.0083"	
70	.0070"	8,200,000

AMS and SAE Peening Shot

Shown in Figures 8 and 9, are the shot sizes listed by their respective ASTM "Nominal" sieve openings. The column listing "Nominal Sieve" openings in inches, refers to the sieve that designates the shot size (.0555" = #550 shot .0331" = #330 shot, etc. The "nominal" sieve identifies both the shot size number and the sieve opening that controls the percentage to be retained on the Cum. Min sieve (90% for AMS and 85% for SAE). By selecting any shot size in Fig. 8 or Fig. 9, then moving up two (2) nominal sieves larger, you have located the sieve representing the top of the size range (the 2% and 5% sieves respectively).

(Example: #230 = Nominal sieve 0234"—two sieves larger = .0331, the 2% or 5% Max sieve for #230.)

Increasing Shot Size - Effect on Impact-Power

As a guideline for those involved in determining the shot size to be specified for use in a given peening application, it will be helpful to know that, for a given velocity, moving up one size larger (one nominal sieve), has the effect of increasing impact-power by approximately two-thirds (67%). Moving up two sizes larger, will increase impact-power almost three times (2.8x).

Examples: #390 (.0394" nominal) to #460 (.0469" nominal) increases impact-power by two-thirds.

#390 (.0394" nominal) to #550 (.0555" nominal) increases impact-power almost three times.

The above increases in impact-power apply to all AMS shot sizes except #70, where the increases would be very much greater.

Coverage: Pellets Per Lb.

Included in Figs. 8 and 9, is a column showing the approximate number of shot pellets per pound, by size. This has significance in peening as it relates to the important factor of coverage. Just as "mass" varies as the cube of a pellet's diameter, so too does the count, but inversely: i.e, a 2:1 size difference = 8:1 mass, but 1:8 count, or, conversely, 1:2 size difference =1:8 mass, but 8:1 count. In peening, the mass requirement must first be satisfied. Without sufficient mass or impact-power to produce the required depth layer of compressive stress, having higher pellet population means nothing.

Decreasing Shot Size - Effect on Impact-Power

Selection of a larger size or smaller size shot to be specified is a choice typically made by the contractor, or the in-house Engineering Department, and, whether large or small, its selection is first based on its ability to produce the desired compressive stress or Almen Intensity.

Thus, concern about decreasing shot size relates strictly to the change in work-mix shot sizing. As stated previously, once new shot is introduced to the system, due to the flaking-spalling phenomenon, it can decrease in diameter one and two sizes before fracture occurs.

Decreasing diameter from a new shot nominal sieve to one sieve below results in impact-power being only 59% of what it was when new. Decreasing shot diameter from new to two sieves smaller means impact-power is only 35% of what it was when new. Referring to Fig. 8, select, for example, size #390, then assign an impact value of 100% to its nominal sieve, .0394"—assign a value of 59% to the .0331" sieve, and a value of 35% to the .0278" sieve. These same numbers (100%, 59%, 35%) apply to any shot size selected, by applying the 100% impact value to the nominal sieve of the selected size.

Note: Flaked/spalled shot retained on the 59% impact-value sieve will have impact-values ranging from 99% to 59%. Shot retained on the second sieve down, will have values ranging from 59% to 35%.

Recognizing Problems

The key to effective and cost-efficient blast cleaning lies in being able to recognize problems as and when they occur. A solid, basic understanding of the principles involved in shot peening, coupled with discipline in following a evaluation program (SPC) will assure an effective and cost-efficient peening operation.

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