PEENING WITH CERAMIC SHOT

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ABSTRACT

Ceramic shot was introduced in 1981. Since then, its use has been developing, particularly on materials such as stainless steel and non ferrous alloys, for example aluminium and titanium alloys in the aerospace industry. The peening properties of the shot stem from the chemical and physical characteristics of the ceramic material. Consolidated experimental and industrial data show that ceramic shot presents a very low breakage. Because of its density, the Almen intensities obtained with ceramic are intermediate to those obtained with steel shot or glass beads. Surface finishing benefits from the low breakage and non polluting characteristics. Two studies on fatigue strength are referred to: one deals with titanium alloy parts and the other with hard steel.

KEY WORDS:

Shot peening - Ceramic shot - Breakage
Almen intensity - Surface finishing

INTRODUCTION

Ceramic shot was introduced in 1981. Since then, its use has been developing, especially in the aerospace industry. We will see, through consolidated experimental and industrial data, how the chemical and physical characteristics of the material translate in terms of breakage rates, peening intensities, surface finishing and most important of all, fatigue strength of the peened parts.

CHARACTERISTICS OF CERAMIC SHOT

Ceramic beads contain approximately 67 % ZrO_2, 31 % SiO_2 and 2 % of minor additions mainly Al_2O_3. The microstructure is based on monoclinic zirconia crystals uniformly enclosed in a silica glassy phase. As shown in Table 1, the physical characteristics combine high density and high hardness.

Table 1 - Physical characteristics of ceramic shot.

True relative density	3.85
Bulk density	2.3 kg
Microhardness7 to 9 GPa under 500 g	

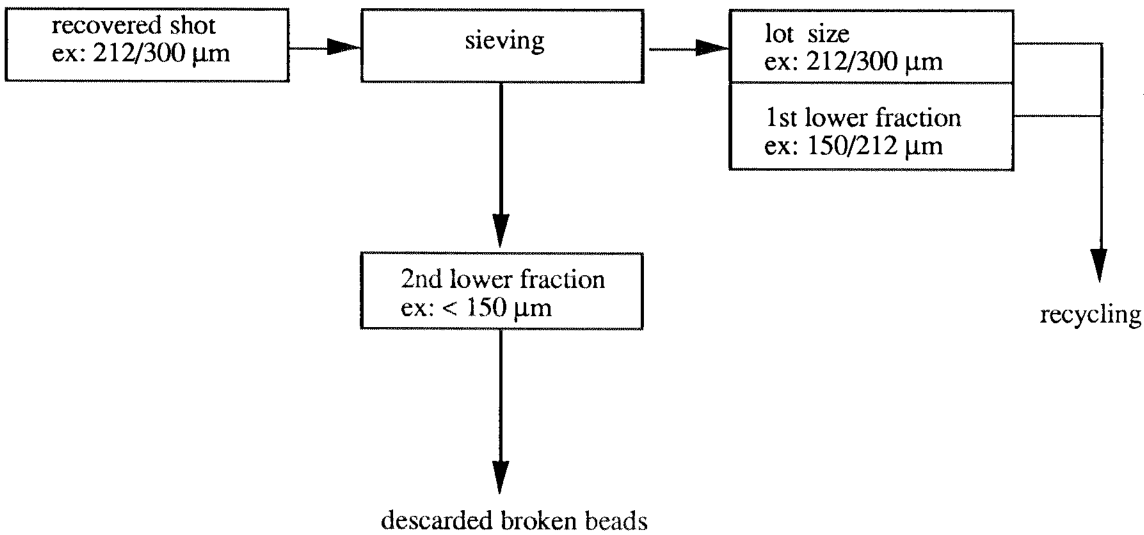
BREAKAGE RATE

Experimental procedure:

Laboratory results, comparing ceramic and glass breakage rates, were obtained using a suction fed air system under the following conditions:

nozzle Ø 8 mm
air injector Ø 4 mm
mild steel aim
aim / nozzle distance 100 mm
impact angle 90 °

The shot was sieved after impact. The beads larger than the second lower sieve size were recycled. The loss or breakage refers to the beads smaller than the second lower sieve size (Fig. 1). This cycle operation, impact, sieving, recycling, loss measurement, was repeated for up to 300 times.



$$\text{Breakage \%} = \frac{\text{initial mass - recycled mass}}{\text{initial mass}} \times 100$$

Fig. 1 - Breakage rate determination - Sieving and recycling principle.

Results:

The influence of Almen intensity (Table 2), impact angle (Fig. 2) and aim hardness (Fig. 2) was investigated, both for ceramic shot and glass beads:

Table 2 - Ceramic shot and glass bead breakage rates (weight percentages) determined for F 30 N and F 50 N intensities - Grain size: 210/300 µm.

	I_A = 30 N (10^{-2} mm) 12 N (mils)		I_A = 50 N (10^{-2} mm) 20 N (mils)	
Number of cycles	ceramic shot P = 2 bars	glass beads P = 2.4 bars	ceramic shot P = 4 bars	glass beads P = 4.4 bars
5	-	2.81	-	22.87
10	-	6.00	2.02	46.37
20	1.52	12.52	3.60	82.15
30	-	19.85	4.57	-
50	3.25	35.25	6.65	-
70	-	51.50	9.07	
100	-	75.24	12.97	
200	5.87	-	-	
300	8.92	-	-	

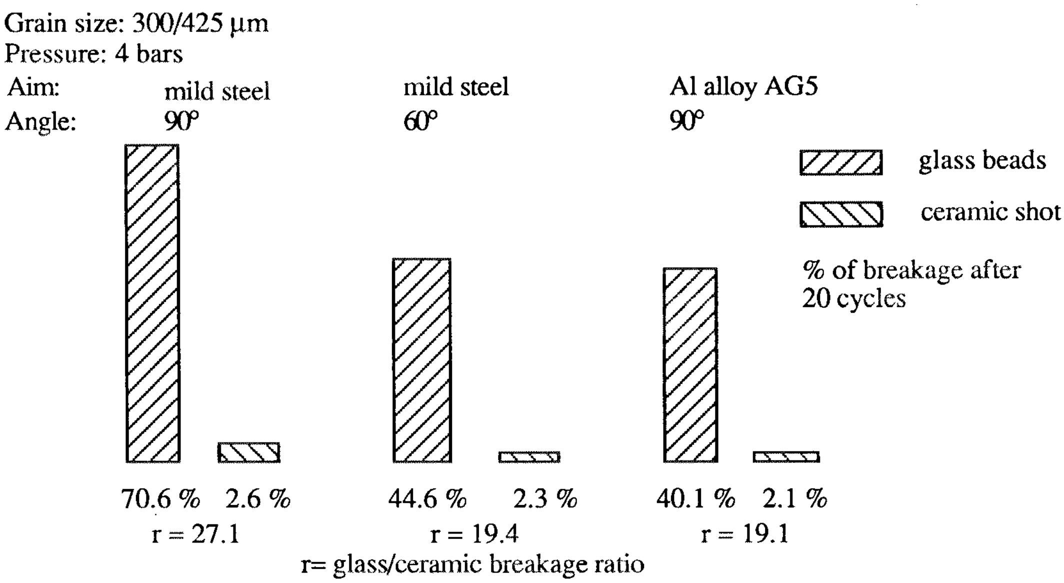


Fig. 2 - Glass / ceramic breakage ratios -
Influence of impact angle and aim hardness.

Ceramic presents a significantly lower breakage than glass. The glass/ceramic breakage ratio:

- sharply increases with peening intensity or pressure,
- slightly decreases with impact angle and aim hardness.

The industrial use of ceramic shot on different materials, such as aluminium alloys, titanium alloys, stainless steel, has confirmed that:

- with a dry process, ceramic consumption is at least 8 to 10 times lower than glass consumption;
- with a wet process, ceramic consumption is at least 25 times lower than glass consumption.

This very low breakage stems from the particular microstructure of the ceramic material. It has 2 major advantages: one economical with the reduction of media cost and one technical relating to improved surface finishing.

ALMEN INTENSITIES

Almen intensities were determined [1] using a suction fed air system equipped with a Ø 8 mm nozzle. The Almen strip to nozzle distance was 100 mm and the impact angle 90°. Almen intensities were established for ceramic shot, glass beads and steel shot. Figures 3 to 5 show the relationship between projection speed and intensities for different grain sizes. As ceramic is denser than glass, it gives higher Almen intensities. It was determined that pressures have to be about 47 % higher when using glass, in order to obtain intensities comparable to those obtained with ceramic for comparable shot sizes. This confirms the 20 % difference, determined by NIKU LARI [2], between Almen intensities obtained at the same pressures.

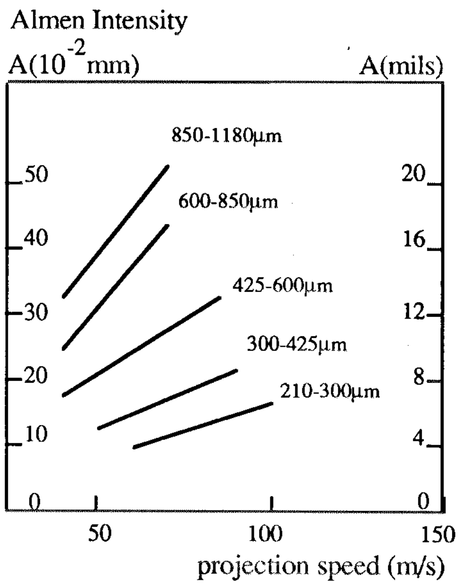


Fig. 3 - Ceramic shot

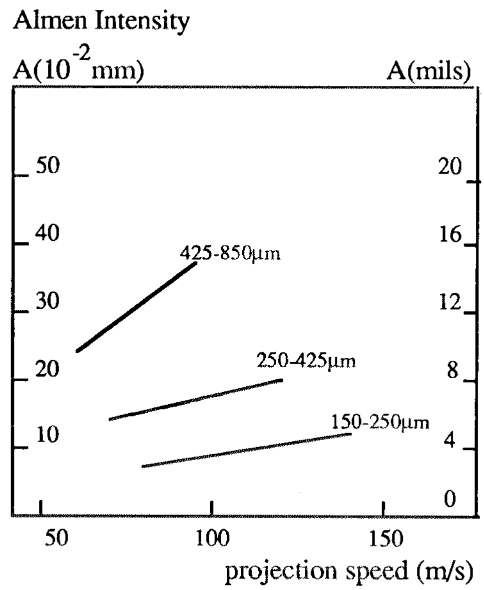


Fig. 4 - Glass beads

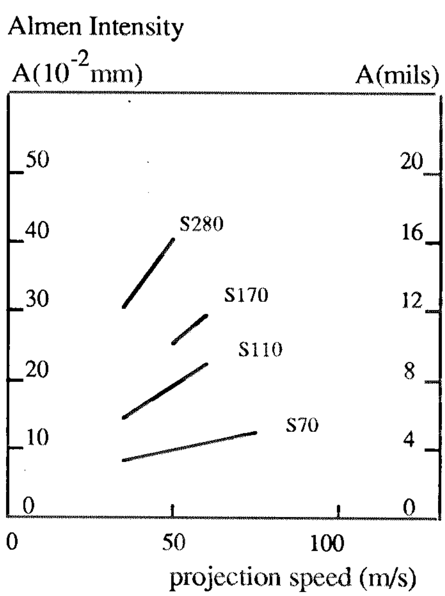


Fig. 5 - Steel shot

Fig. 3 to 5 - Correspondance between projection speed and Almen Intensities for Ceramic shot, Glass beads and Steel shot.

A similar trend is also observed when using wet systems. Fig. 6 represents the intensities obtained with glass and ceramic. This data was established for an industrial application of airfoil overhaul peening.

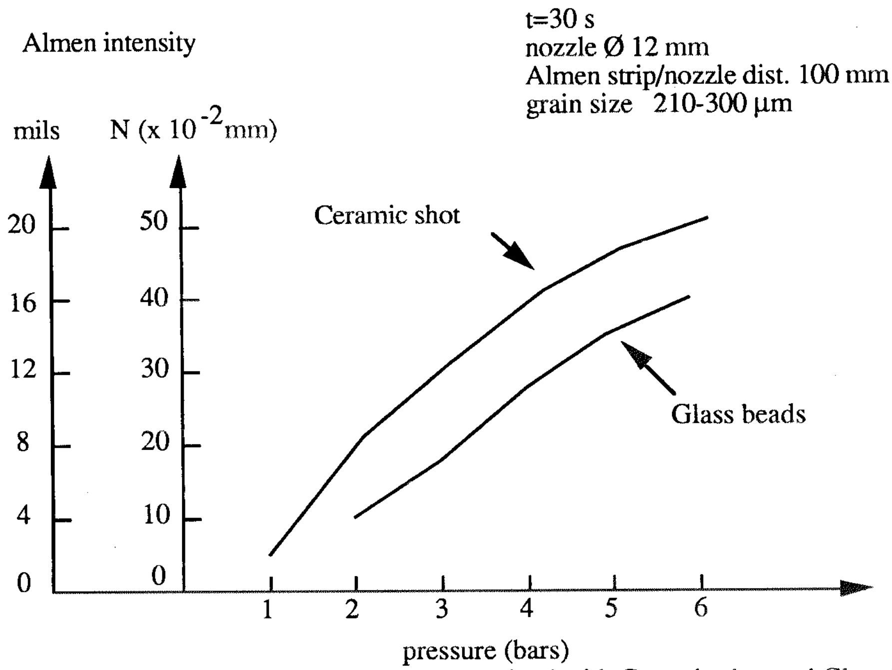


Fig. 6 - Wet process - Almen intensities obtained with Ceramic shot and Glass beads.

SURFACE FINISHING OF PEENED PARTS

Both corrosion and fatigue strength are closely related to surface finishing. Ideally the surface must prevent a regular finish with a low roughness. Surface contamination, either with chemical elements or embedded particles, should be minimal. The effect of pressure and shot size on surface roughness was determined using ASTM 316 Stainless Steel (Fig. 7).

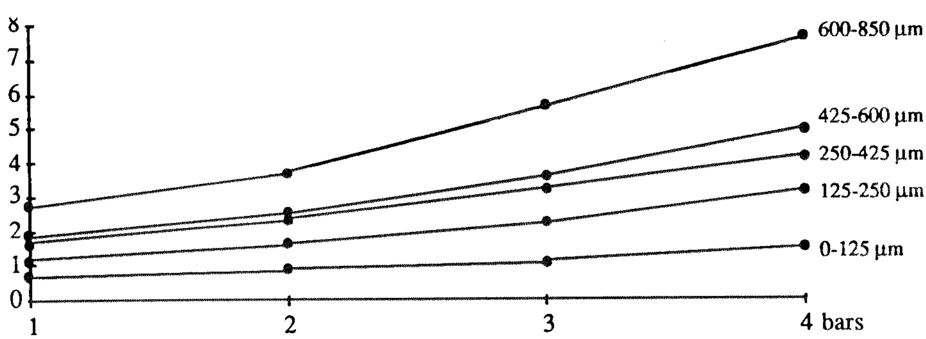


Fig. 7 - ASTM 316 Stainless steel - Ceramic shot -
Effect of pressure and shot size on surface roughness.

The surface roughness:

- increases with pressure for a given shot size,
- increases with shot size for a given pressure,
- decreases when using larger shot for a given Almen intensity.

Industrial results obtained with a direct pressure system on ASTM 304 stainless steel show that ceramic beads give a lower surface roughness than glass beads
(Table 3).

Table 3 - Surface roughness on ASTM 304 stainless steel. Pressure = 4 bars

	Glass beads	Ceramic shot
grain size	125/177 µm	70/125 µm
surface finishing Ra 1.14 µm	0.8 µm	
Rmax	13.14 µm	7.75 µm

Surface pollution of peened parts

Non ferrous alloys and stainless steels peened with steel shot need to be decontaminated. The thin layer of iron deposited on the surface or the embedment of small metallic particles can result in corrosion defects. No decontamination is needed when using non metallic, oxide base, media. Though their use is common, it can in some cases induce surface defects, as for example embedment in hard metals. The extend of this pollution is directly related to breakage. [3]

FATIGUE STRENGTH

The purpose of shot peening is to increase fatigue strength. All economical or technical factors set aside, the fatigue results condition the choice of media. Several studies have shown that a gain in fatigue strength was obtained with ceramic shot, especially on hard materials. WOHLFAHRT [4] has shown that hard shot considerably enhances the magnitudes of both the maximum stress and the surface stress. This of course influences fatigue strength.

Ti - 6 Al - 4 V [5]

This study was conducted by FRANZ and OLBRICHT [5].

Experimental procedure

Ti - 6 Al - 4 V specimens were shot peened using compressed air jets. Three different types of media were used:

steel shot	S 170 and S 390
ceramic shot	425-600 µm and 850-1180 µm
glass beads	180-300 µm

The investigated Almen intensities ranged from 15 N (10^{-2} mm) to 40 A (10^{-2} mm).
Single stage alternating bending tests were conducted (R = -1) and Wöhler diagrams were drawn.

Results:

Using conventional media, glass or steel, the most pronounced improvement in the fatigue limit (Fig. 8) was from ± 410 to 470 N/mm^2 (+ 15 %). It was observed using steel shot, S 170, at 15 A (10^{-2} mm). The limit was extended to ± 510 N/mm^2, with ceramic shot (425-600 µm at 25 N (10^{-2} mm)). Fatigue life (Fig. 8), for the amplitude of ± 550 N/mm^2 was improved by a factor of 15 with conventional media (steel shot, S 170, at 40 A (10^{-2} mm)) and by a factor of 39 with ceramic shot (425 - 600 µm at 25 N (10^{-2} mm)).

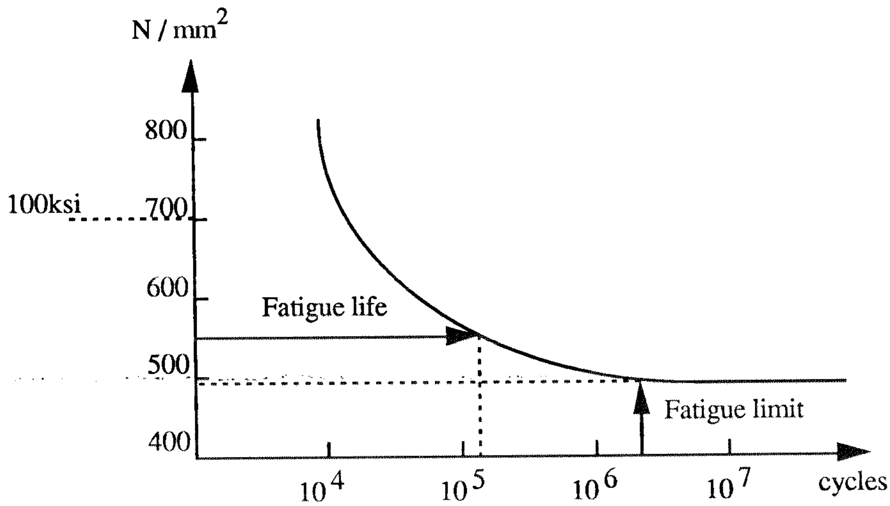


Fig. 8 - Wöhler diagram - Principle.

High strength steel [6]

Experimental procedure:

Fatigue and tensile specimens of 300 M steel were machined in the longitudinal grain direction from bar stock and heat treated to 280-300 ksi (1960 - 2100 N/mm^2, RC 53-55). Average mechanical properties were as follows:

Tensile strength		Yield strength		Elongation
290.4	ksi	250.2	ksi	11.3 %
2033	N/mm^2	1751	N/mm^2	

The specimens were peened using different conditions according to Table 4. Fatigue tests were conducted on fifteen groups (6 specimens per group) of peened specimens and one group in as machined conditions. The specimens were subjected to a two level block spectrum shown below. The maximum stress applied was 208 ksi (1456 N/mm^2).

Two level block spectrum:

level	Maximum	Minimum	Number of cycles
1	100.00 %	0	1
2	67.31 %	0	1

Results:

The results are tabulated in Table 4. A significant increase in cycles to failure for 300 M steel was obtained by peening with ceramic shot and hard steel shot at low intensities and using small shot sizes. It seems that these conditions maximized compressive stress at the surface, and that it became less effective as size and intensity were increased. Examination of the fracture surfaces showed that the failure origin was always at the surface. Nital etch examination on the edge of the peened surfaces showed strain lines in direct proportion with peening intensity and shot size. These strain lines are believed to be a result of plastic deformation of the material.

It was concluded that optimum amount of plastic deformation, as obtained at an intensity of 6 A (mils) enhanced the maximum compressive stress at the surface and in turn, the increase in fatigue life. Significant deformation, as for 16 A (mils), reduced the fatigue life.

Table 4 - Shot peening parameters and results - 300 M heat treated to RC 55 - 200 % coverage.

SPECIMEN	SHOT HARDNESS	SHOT SIZE	PEENING INTENSITY (mils) *	FATIGUE CYCLES **	% CYCLES INCREASE ***
CONTROL	NO SHOT PEENING			16 465	
STEEL SHOT					
1	RC 46	S 170	6 A	18 513	12
2	RC 46	S 170	10 A	17 974	9
3	RC 46	S 230	6 A	24 731	50
4	RC 46	S 230	10 A	23 073	40
5	RC 46	S 230	16 A	18 823	14
6	RC 65	S 170	6 A	29 204	77
7	RC 65	S 170	10 A	25 086	52
8	RC 65	S 230	6 A	27 735	56
9	RC 65	S 230	10 A	23 672	44
10	RC 65	S 230	16 A	19 353	18
CERAMIC SHOT					
11		S 170	6 A	26 689	62
12		S 170	10 A	20 189	23
13		S 230	6 A	26 212	59
14		S 230	10 A	20 631	25
15		S 230	16 A	18 119	10

* 6 A (mils) ~ 15 A (10^{-2} mm)
10 A (mils) ~ 25 A (10^{-2} mm)
16 A (mils) ~ 40 A (10^{-2} mm)

** average value of the group

*** % Fatigue cycle increase = $\frac{\text{specimen - control}}{\text{control}} \times 100$

CONCLUSION

The industrial use of Ceramic shot since 1981 has confirmed its performance in shot peening applications. Ceramic shot presents a very low breakage rate which translated in two advantages, one economical and one technical relating to improved surface finishing. The Almen intensities are intermediate to those obtained with glass beads and steel shot. Several studies have shown that, compared to other peening media, a gain in fatigue strength was achieved, especially on hard materials. Ceramic shot is now included in the major norms and specifications dealing with shot peening procedures and media, as for example:

SAE	Size classification and characteristics of ceramic shot for shot peening
AMS 2431	Peening media - General requirements
2431/7	Peening media - Ceramic shot
MILS 13165 C	Shot peening of metal parts

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