Peening with fused ceramic beads

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Introduction

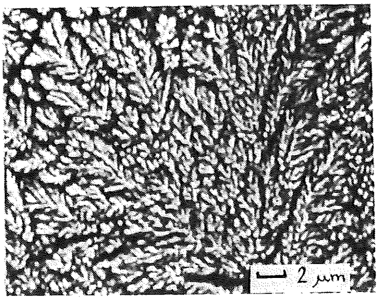
The use of fused ceramic beads in shot peening and peen forming tends to develop, especially in the aircraft construction. Their physical and mechanical characteristics differ much from both conventional media: glass and cast steel beads (1) (2).

The macroscopic effects of peening and the behaviour of various shots can be forecasted, in a qualitative or semi-quantitative manner. So, it is possible to take advantage of the specific properties of the fused ceramic shot in defining the necessary adjustment to the working stock and to the operation parameters. The following lines offer an attempt at forecasting simple effects on ALMEN intensity, surface roughness or surface pollution.

The internal stress pattern can be calculated by recent models (6) but their complexity is beyond the scope of this technological approach.

Characteristics of fused ceramic beads

This product* is manufactured by fusing a mixture of oxides at high temperature. It contains 67 % ZrO_2, 31 % SiO_2 and 2 % minor additions, mainly Al_2O_3. Their specific gravity is 3,75.



Pict. 1: Typical microstructure of fused ceramic beads

The microstructure is based on monoclinic zirconia crystals (microhardness 9 GPa) uniformly embedded in a silica glass (micro-hardness 7 GPa) as shown in picture 1. A high toughness meaning a high resistance to shocks (2), derives from this structure.

This shot combines high hardness and specific gravity, low breakage at use in spite of a non-metallic constitution.

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*ZIRSHOT ™ from Société Européenne des Produits Réfractaires

Almen Intensity

The Almen Intensity is a convenient manner to characterize the peening effect. It is used to determine the operating parameters and then helps to control them. But it is not directly related to the internal stress pattern.

For a given shot type and mean size D, the projection conditions act directly on its mean velocity V at the impact point. We have correlated the Almen A intensity Ia to size and velocity in an empirical relation taking the following form

$$Ia = a \cdot D^m \, V^n$$

The a, m and n constant factors, depending only on shot type for a 90 degree peening angle, are (Ia in 10^{-2} mm, D in μm and V in m/s).

Shot	m	n	a
Fused Ceramic	1,27	1,06	11,95 10^{-5}
Glass	1,33	1,08	5,760 10^{-5}
Cast Steel (50 HRC)	1,00	0,61	322,5 10^{-5}

The size and velocity exponents of "brittle" shots, like fused ceramic and glass are almost identical. But a is twice as high for ceramic than for glass. This could be due to the combination of:

- the different specific gravities. The rate fused ceramic / glass is 1.45.
- the differences in elastic moduli (E. Young and ν Poisson). The stiffness modulus E / (1- ν^2), which takes part in the Hertzian elastic stresses developped during impact, is 1,33 higher for fused ceramic than for glass.
- the much lower tendancy to waste energy by breakage for the fused ceramic beads.

For steel shot, the constant factors are very different. The Almen Intensity appears to be less sensitive to variations in bead diameter or impact velocity. Part of the incident energy is probably used by the work hardening in the first cycles. Closer analysis reveals that the velocity exponent n is higher (0.75) for pre-ground steel shot.

Surface Roughness of peened parts

This characteristics is an external indication of the reaction of a peened metallic part. Various parameters are in use to describe the state of surface. We have chosen to retain Ra, the mean arithmetic rugosity. This value is usually used to qualify the surface although it is not necessarily related to the crack initiating flaws.

Results have been obtained on cast iron, carbon steel and TA6V titanium alloy. Fig. 2 shows the relation between Ra / D and the Damage Number N, as suggested by Al Hassani (3) (4). The dimensionless Damage Number is:

$$N = \rho \frac{v^2}{y}$$

where y is the yeld stress
ρ is the specific gravity of shot

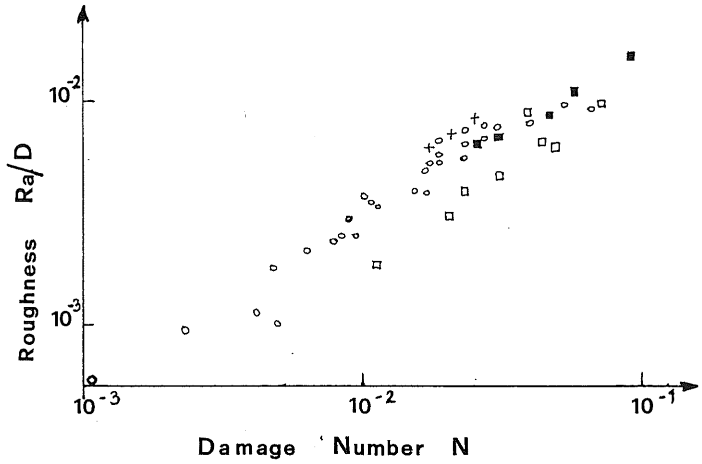
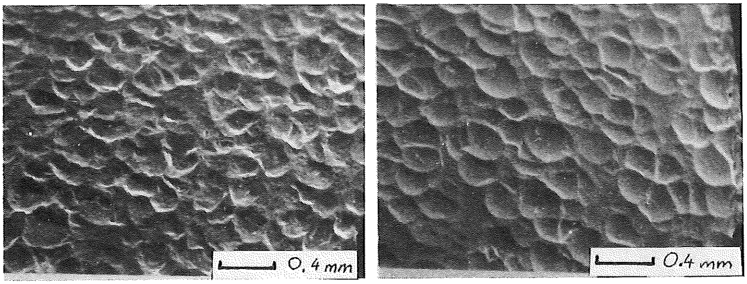


Fig. 2: Dimensionless surface roughness for peened surfaces at 200 % coverage. Dry peening with (o) fused ceramic beads, (+) glass beads, (□) new steel shot at 50 HRC, (■) pre-ground steel shot.

Ra is proportional to $D \cdot N^{0,7}$

New steel shots give lower Ra in our case but, with pre-ground shots, the general condition appears to be met. This is surmised to be due to the deformation of soft shot in the generally hard metallic surfaces used in these tests. But even for low hardness parts, one can observe facets on used steel shots. They modify the state of surface (Picture 3).

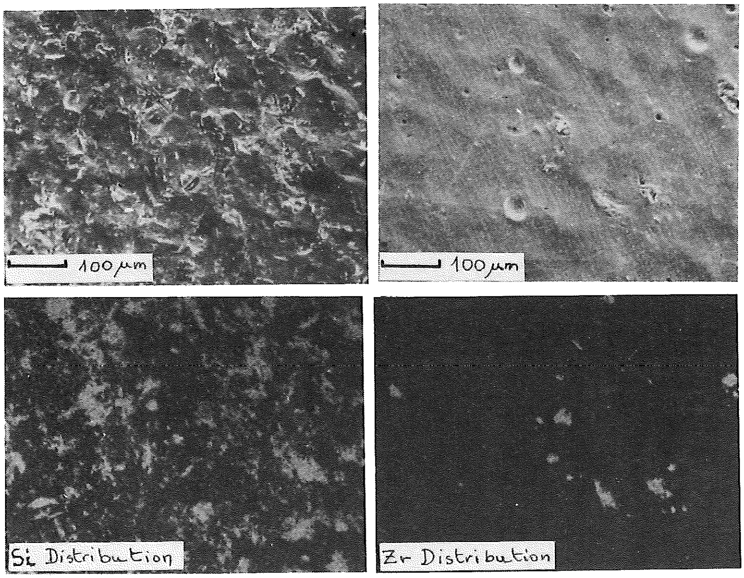
Combining this result with the empirical relation on the Almen Intensity, it is easy to verify that at constant Ia, the lowest Ra values are obtained with the largest mean shot size.



Pict. 3: Facet "prints" on A U4G Aluminium alloy. Peening with steel shots (left, BA 600 size) compared to fused ceramic beads (right, 0.85 - 1.18 mm size).

Surface Pollution of peened parts

Non-ferrous alloys, peened with steel shot, need to be decontaminated. Indeed, their surface is covered by a thin film rich in Fe and C. In soft aluminium alloys, embedment of small metallic particles, responsible of localized corrosion pits can also be observed.



Pict. 4: TA6V surface peened with glass beads (left 0,15-0,25 mm size, Ia = 0,27 mm) or fused ceramic beads (right, 0,30-0,425 mm, Ia = 0,35 mm). Dry peening, 200 % coverage.

The use of oxide base media is common. But this does not mean a defect free surface in all cases. As shown by picture 4, embedment is common in hard metals, like TA6V titanium alloy.

Broken pieces, or small satellites sticking on the beads, are retained on the peened surface, due to the high elastic recovery of this alloy. In this case, the extent of pollution is directly related to breakage.

Adjustments of peening parameters
The shot velocity appears to be an essential peening variable. Practically, when peening with compressed fluids, only pressure P is known and monitored. Experimentally, in dry peening, a correlation has been found between velocity and operating parameters. For a venture-type nozzle, the relation sounds:

$$V = b \cdot \rho^{-1/2} D^{-1/3} P^{3/4}$$

The constant b depends mainly on nozzle geometry. Our measurements have shown that there is almost no velocity decrease between 100 and 300 mm from nozzle outlet.

It is important to note that, when changing the media type, peening pressure should be changed as $\rho^{2/3}$, to get the same velocity. The surface coverage is another important point. Numerical simulations, confirmed by experimental results, have shown that coverage depends mainly on the size and number of projected beads B. Considering a full coverage (98 % +) the typical broad size distribution, as observed in industrial products, does not seem to play any role.

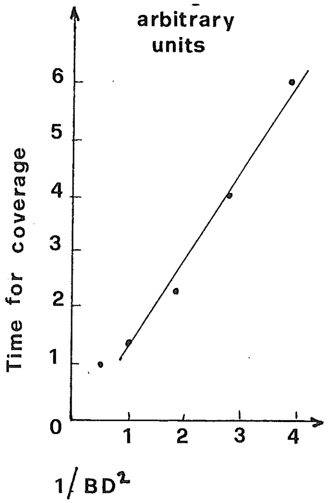


Fig. 5: Experimental coverage curve.

As shown in figure 5, the time t to reach full coverage is:

$$t = \frac{c}{BD^2} \qquad (c = \text{constant})$$

This expresses the experimentally verified fact (5) that the diameter of the print is proportional to the diameter of the shot.

A good knowledge of the throughput of each nozzle is essential. It increases, in venture type nozzles, when shot diameter or specific gravity decreases.

Technical adjustments of the blasting machines

In dry peening machines, brittle shot breaks. When using ceramics, the broken particle sorter has to be adapted. Indeed, the mean size of broken fused ceramic shot is 5 times larger than for glass beads of the same diameter. In wet blasting cabinets, the fused ceramic beads can only be used safely if separate pumps are installed on the media and water circulating loops. If not, the denser ceramic beads settle down and the media concentration drops.

In wheel blasting machines ceramic beads can be used but, to limit breakage to a reasonable extent,
- peripheral velocity has to be kept under 60 m/s
- a pneumatic preaccelerator is highly advisable.

In all cases, for fused ceramic beads, breakage varies as $V^{1.5}$ approximatively. Of course, it is interesting to choose, for a given Almen Intensity level, the largest size and lowest velocity.

Conclusion

The use of empirical relations or simple impact models draws attention to important variables of the peening process. The most important one is the shot velocity. The given equations allow to adjust the peening conditions to the use of fused ceramic beads and making use of their original characteristics.

References

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