High density ceramic shot for peening application

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Introduction

Ceramic shots are used in a large range of industrial peening applications, such as automotive suspension springs[1], transmission gears[2], aluminium aircraft wheels[3] , titanium turbine engine blades, titanium biomedical implants[4] where significant fatigue strength improvements have been demonstrated. Peening process results are greatly influenced by peening conditions such as media type, velocity, exposure time, but also by the nature and processing history of material workpiece [3]. Recent development to use high performance metallic alloys may require evolutions in peening media design to fully take benefit of peening for lightweighting and optimized functional performance.
Ceramic shot features such as hardness, specific gravity, impact strength can be tuned and enhanced up to an unmet level. The aim of the study is to illustrate how the increase of density and hardness of new ceramic shot should open new range of performance for shot peening applications.
Ceramic shot, steel shot and rounded steel cut wire were fully characterized (shape, hardness, size, density…). AISI 1070 carbon steel plates were peened under several conditions of pressure in direct pressure cabinet and in wheel turbine equipment. Process parameters such as shot velocity, coverage rate, mass flow rate, and Almen intensity were determined. All those parameters were related to residual stress profile in order to identify the impact of media properties on final results, in comparative conditions. Surfaces were characterized after peening. Finally, media lifetime was measured in some representative conditions.

Methodology

Ceramic shots Zirshot HDC (Saint-Gobain), with size from 0.4-0.6 mm (ZC400) and 0.9-1.1 mm (ZC900) were studied and compared to high carbon cast steel shot S330 -540HV, and conditioned steel cut wire SCW-G3-0.9mm - 700HV. Almen strips C (AISI 1070, 45-48 HRC) were shot peened under several conditions in direct pressure equipment (residual stress evaluation, peening effect on surfaces), a wheel turbine machine and a specific pneumatic impact shot tester equipment (media lifetime measurement). Particle velocity was assessed with Shotmeter (Tecnar Automation). Shot media and blasted surfaces were observed using a scanning electron microscope (TM-1000 Hitachi). Roughness measurement was performed using a Mitutoyo SJ-210 roughness meter. The results presented are the mean value of 3 measurements for each peening condition. Shots shape analysis was performed using Camsizer XT (Horiba). Vickers hardness was measured with Buehler MicroMet 6030 equipment (with 500gF for ceramic shots, 300gF for metallic shots). X-Ray residual stress analyses were carried out with an X-Ray diffractometer X3000 (Cr Kα radiation, $\sin^2\theta$ method).

Results and analysis

Shot analysis - basic characterization

Main properties of S330, SCW-G3-0.9mm and ZC900 are reported on the Table1. One can observe that the density of Zirshot HDC is significantly higher than conventional ceramic shot (for example 3.8 g/cm3 for Zirshot). The Aspect Ratio, defined by the ratio of the minimum to the maximum diameter, gives an indication of the elongation of the spherical particles. (a value of 1 would be for a perfect sphere whereas a value below 0.8 is conventionally considered as misshaped shot). Zirshot HDC exhibits the lowest amount of misshaped shots and SEM inspection reveals highly smooth and homogeneous surface as compared to other tested media.

Media selection among commercial grades has been done to compare equivalent sizes. Distribution is reported in the figure 1. The size distribution of ZC900 is however narrower and bit coarser than other blasting media of the study.
Finally, ZC900 is significantly harder than the steel shot media (68% harder than SCW-G3-0.9mm). This level of hardness will ensure a high energy transmission during the peening process, and will allow an effective treatment of hard metallic alloys such as carbonitrided steel, superalloys…

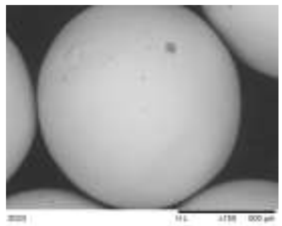
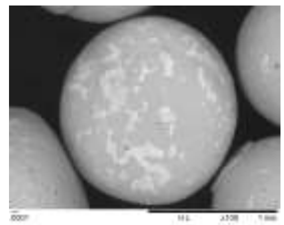
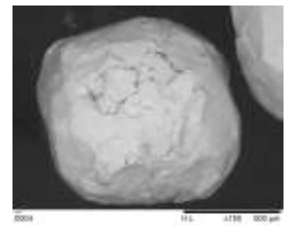
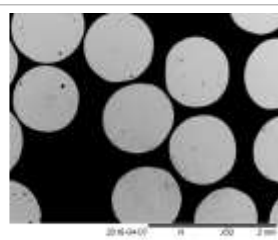
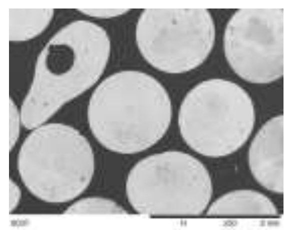
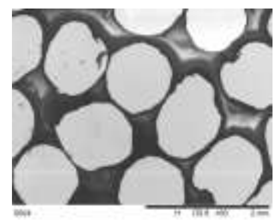
	Zirshot HDC ZC 900	High carbon steel S330	Rounded Steel cut wire SCW-G3 0.9 mm
SEM images			
Cross section			
Shape analysis (% of shots with B/L< 0.8)	1.6%	19.4%	6.3%
Size(mm)	0.9-1.18	0.85-1.18	0.85-1.18
Density	6.2	7.4	7.4
Hardness	1180 HV (70 HRC)	540 HV (50 HRC)	700 HV (60 HRC)

Table 1 : Main properties of Zirshot HDC, cast steel shot and conditioned cut wire

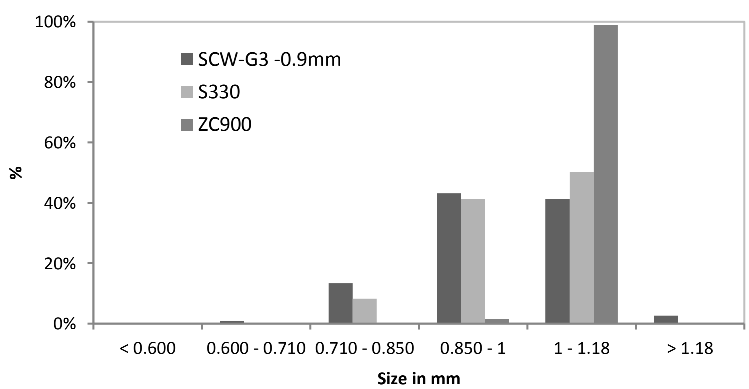


Figure 1 : Size repartition

Media behavior in air pressure equipment

We discuss in this section the ability to propel ZC900 by air pressure in comparison with S330 and SCW-G3-0.9mm. Almen intensity and particle velocity were measured as a function of blasting pressure (Figure 2 and Figure 3).

When propelled in air-suction equipment at a given pressure, ceramic media ZC900 can reach higher velocity than SCW-G3-0.9mm steel media thanks to better aerodynamic properties.

At 5 bars, metallic shot velocity is overpassed by 28% with ZC900. As ZC900 has also a significantly higher hardness than SCW-G3-0.9mm, the resulting Almen level for a given pressure is also higher with ZC900. As an example, it was possible to reach 0.23mm-C (0.80mm-A) for ZC900 (propelled at 5 bars in air-suction system) versus 0.53mm-A with for both types of steel media. Those results reveal the high level of energy transmission to the target obtained with Zirshot HDC.

Media lifetime was assessed in specific impact air-blasting test equipment. A 100gr load of media was recirculated for several hours in this small equipment (blasting distance =10 cm, angle =90°) at several Almen levels. Mass flow rate was measured in order to estimate the cycling rate. Almen strips C were used as target material (Hardness = 45-48 HRC). The broken media are removed by suction. We measured the number of cycles to wear 20wt% of the working mix media. Results are presented on Figure 4.

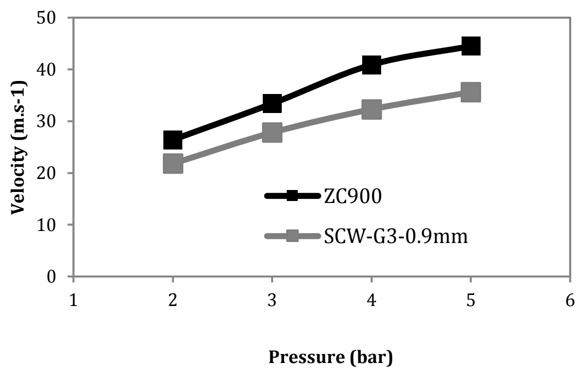


Figure 2 : Particles velocity as a function of pressure (Nozzle diameter:0.8 mm, air suction)

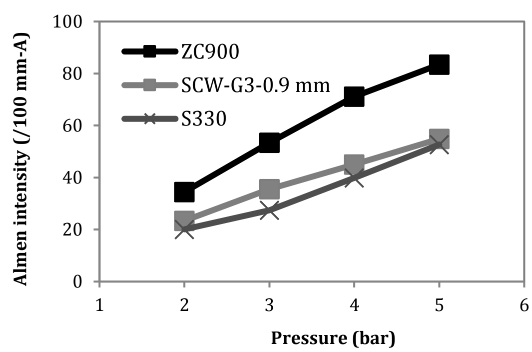


Figure 3 : Almen intensity as a function of blasting pressure in pneumatic equipment
(Nozzle diameter:0.8 mm, air suction)

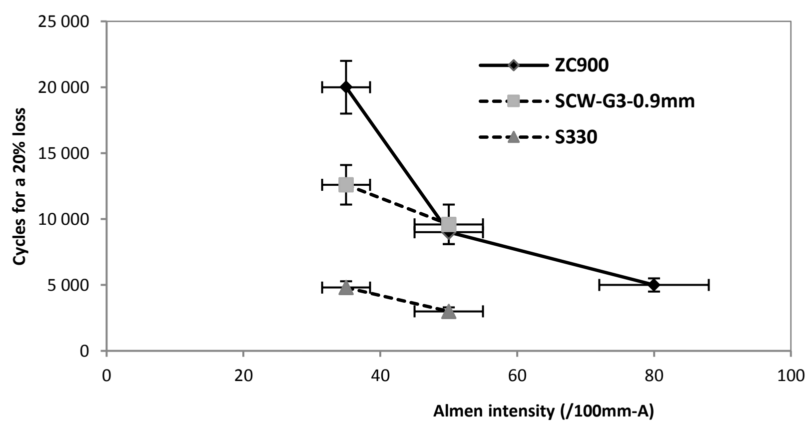


Figure 4 : Consumption as a function of Almen intensity for various blasting media

S330 clearly exhibits a lower durability than other blasting media (both at 0.35mm-A and 0.50mm-A). Whereas consumption of ZC900 is lower than SCW-G3-0.9mm at 0.35mm-A, the cycling rate to reach a 20% loss at 0.50mm-A is clearly in the same range for both products. At 0.50mm-A and with ZC900 in a pneumatic equipment, 10 000 cycles are required for a 20% media weight loss. This corresponds to 0.002% of loss/cycle. This value is actually low and is in the range of consumption of conventional ceramic blasting media used at significantly lower Almen level (0.20mm-A for a comparable size). The consumption of ceramic ZC900 at 0.23mm-C is comparable to the one of S330 at 0.35mm-A.

Test in wheel turbine equipment

Considering the fact that conventional ceramic shot (e.g. Saint-Gobain Zirshot and Zirblast) cover already a significant range of industrial applications by wheel turbine blasting, the enhancement of density, hardness and toughness of new ceramic Zirshot HDC should extend the domain of these applications. Zirshot ZC400 was tested in a wheel turbine machine (wheel diameter 340 mm, 7.5 kW) and compared to Zirshot Z425. Almen intensity is plotted as a function of tangential velocity on Figure 5, and amperage as a function of Almen intensity on Figure 6.

Figure 5 shows that the Almen intensity is 30% higher for ZC400 at a given tangential speed (i.e., wheel rotation speed). At 60m.s^{-1}, it becomes possible to reach 0.33mm-A, with a low wheel amperage as shown on Figure 6.

A consumption trial (8hrs running) was performed with ZC400 in wheel turbine and compared to Z425 for a comparable range of Almen intensity (316L stainless steel plates as a target). Results are reported on Table 2.

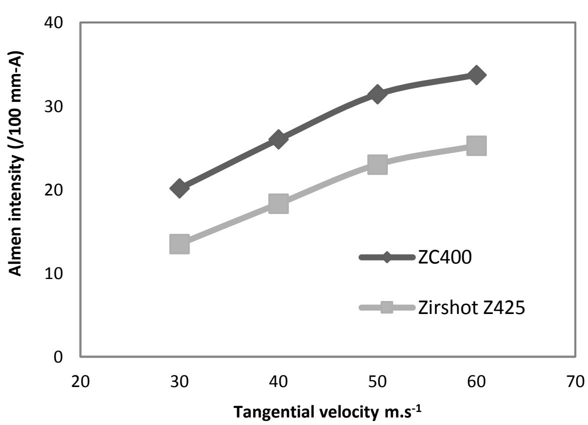


Figure 5: Almen intensity as a function of tangential velocity

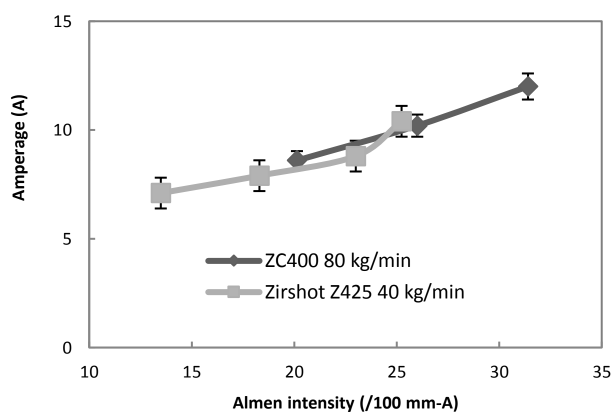


Figure 6: Wheel amperage as a function of Almen intensity

Blasting media	Z425	ZC400
Almen intensity (/100mm-A)	17	19
% of loss/cycle	0.047	< 0.005

Table 2 : Consumption for different blasting media and Almen intensity in wheel blast equipment

At 0.19mm-A, the consumption of ZC400 is very low compared to Z425 (one level of magnitude) and almost negligible. Such performance give the opportunity to use Zirshot HDC in wheel turbine either as a regular ceramic shot, with higher longevity or to reach high Almen level that could not be met with conventional ceramic shots.

Residual stresses generation and surface condition

Residual stress and surface analysis were investigated in order to assess the potential benefits of ZC900 for peening applications (fatigue lifetime of shot peened parts is mainly impacted by stress profile and roughness level). Almen C strips were peened in a direct pressure equipment at a given particle speed, i.e., 35m.s^{-1}. Coverage rate was 125%. Stress profile and roughness are reported on Figure 7 and Figure 8. It is first confirmed in direct pressure equipment that for a same particle speed, it is possible to reach higher Almen level when blasting with lighter and harder ceramic media. It is also interesting to notice that the Almen level is also higher when blasting with SCW-G3-0.9mm than with S330 (the last being less hard). The level of compressive stress at the surface is equivalent for all media (σ=-540MPa). It is admitted that this value is usually tightly dependent on the nature of the target and its processing history. However, the general stress profiles are different: ZC900 leads to a more intense and deeper profile: the maximal stress level is 100MPa higher with ZC900 than metallic media in these peening conditions. The affected depth of the treatment is similar for SCW-G3-0.9mm and ZC900, and it is lower for S330.

SEM pictures of AISI1070 plates blasted at 125%, 35m.s^{-1} are reported on Figure 9. It should be noticed that the tests were performed with fresh product only. In good agreement with Figure 8, the roughness is lower with S330. This is mainly explained by the hardness ratio between media and target, close to 1 for S330, and in the range of 1.25 with SCW-G3-0.9mm and 1.5 with ZC900. SCW-G3, probably due to a poor surface state, generates a deep roughness profile. ZC900 is intermediary, with a roughness level close to S330 for a given Almen level, and a typical surface state, composed of very homogeneous indents.

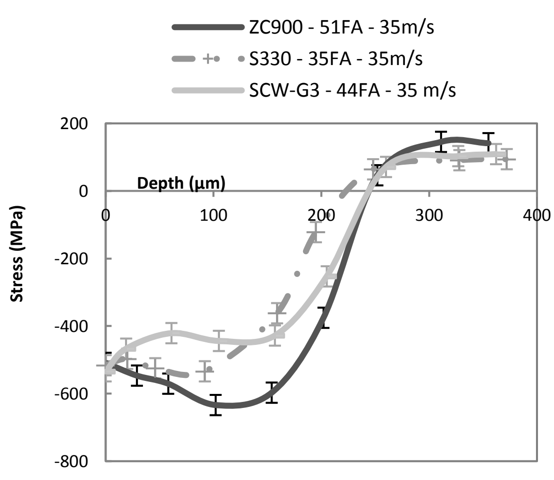


Figure 7 : Residual stress profiles on peened AISI1070 with ZC900, S330 and SCW-G3-0.9mm at 35m.s^{-1}, 125%

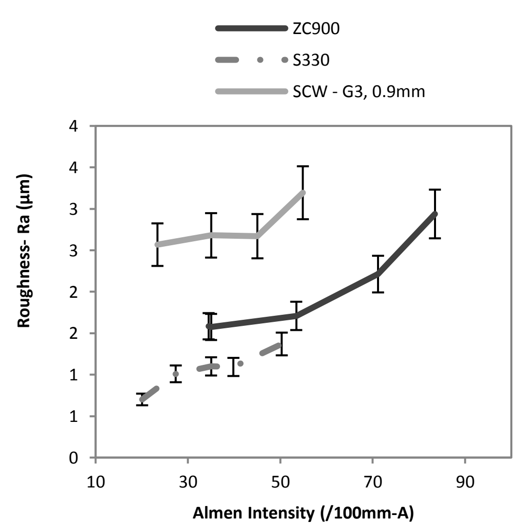


Figure 8 : Roughness profiles on peened AISI1070 with ZC900, S330 and SCW-G3-0.9mm at 35m.s^{-1}, 125%

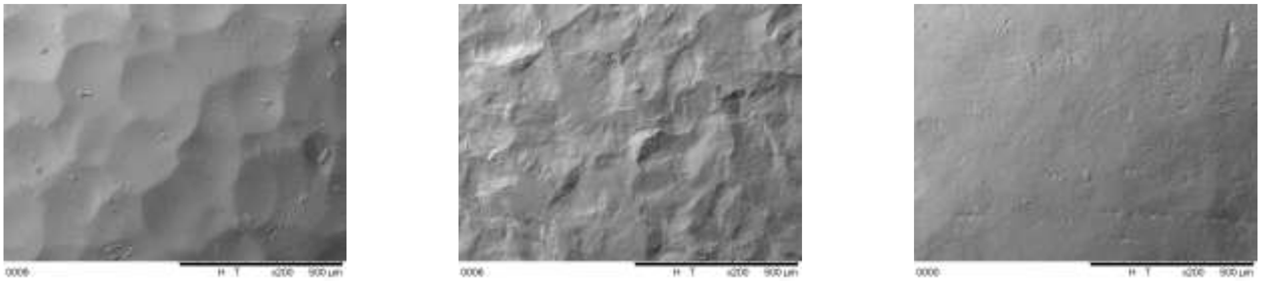


Figure 9 : AISI 1070 peened surfaces at Almen 0,35mm-A and 125% coverage with ZC900 (left), SCW-G3-0.9mm (center) and S330 (right).

Conclusion

Optimization of ceramic media properties (density, hardness, toughness) leads to superior results in terms of residual stress generation while keeping surface integrity, combined with outstanding media behaviour (impact strength, processability). The level of transmitted energy overpasses any prior shot peening references. Intense and deep residual stress profiles can be achieved in throwing conditions compatible with industrial applications. In addition, this new ceramic media exhibits high sphericity, smoothness and inertness and can thus be applied for peening on high strength steel and superalloys to further enhance the performances of mechanical components.

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