Fine, Hard, and High Density Ceramic Beads for Shot Peening

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Abstract
We investigate the use of new high density, fine, and hard ceramic beads for shot peening. By studying the effect of such media on a series of representative alloys, we show that they can impart very efficiently intense residual stresses, especially at the surface. Due the higher hardness of the media compared to the treated alloys – even carburized steel – this efficient modification of the sub-surface is accompanied by a roughness modification that is strongly dependent on the intensity of the treatment. The combination of the intense residual stresses and controlled surface topography modification brings some new opportunities for improving the shot peening process of different alloys.

Keywords Fine shot peening, ceramic shot, roughness, residual stress.

Introduction

Shot peening with hard media on a metallic substrate is a standard method to obtain a controlled surface roughness, as well as to induce compressive residual stresses. The media size is typically from 10µm to 1000µm, and they can be metallic shots, glass or ceramic beads [1]. Ceramic beads are selected when high hardness or no metallic contamination is needed, and provides significantly longer lifetime than glass media. Standard ceramic media have a density of 3.9g/cc, and a Vickers hardness of 700HV. As the hardness ratio of media to substrate is a key parameter for shot peening [2], it can be advantageous to use even harder media. Hence, higher hardness and higher density ceramic media with a size of 400 – 1200µm were introduced a few years ago, with density of 6.2g/cc – close to metallic media – and hardness of nearly 1200HV [3].

The use of fine media for shot peening has been studied for many years, and confirmed the interest to increase the lifetime of the treated parts. For instance, corrosion resistance was reported to be increased on TA6V [4]; fatigue resistance was also improved an aluminum alloy [5,6], or steel [7,8]. Yet these studies considered either standard ceramic shots with moderate density (3.9g/cc) and hardness (700HV), or metallic shots. The use of finer, denser, and harder ceramic media is still to be explored.

In the following, we evaluate a new ceramic media with high density (6g/cc), hardness (1250HV) and sizes of 300µm and below. In order to estimate the interest for a broad range of application, a selection of alloys was considered, with very wide hardness levels, from aluminum to carburized steel.

Experimental Methods

High density, fine ceramic shots Microshot YZ (Saint-Gobain) were tested for shot peening application. The media size and main properties are reported on Table 1. The selected Almen intensities correspond to low to moderate pressure: from 1 to 2.5 bar.

Media	Type	Density	Hardness	Size	Almen tested
YZ50	Ceramic	6 g/cc	1250 HV	50 µm	0.07 and 0.10mm N
YZ100	Ceramic	6 g/cc	1250 HV	100 µm	0.10 and 0.15mm N
YZ300	Ceramic	6 g/cc	1250 HV	300 µm	0.06 ; 0.10 and 0.15mm A
ZC600	Ceramic	6.2 g/cc	1180 HV	600 µm	0.25mm A
S110	Cast steel	7.8 g/cc	600 HV	300 µm	0.10 and 0.15mm A

Table 1: Media, main characteristics, and Almen intensities used for the shot peening tests

Shot peening tests were performed on different flat samples: aluminum 7075-T6, titanium TA6V, AISI1070 (45-48HRC) steel, and 16MnCr5 carburized steel. We used a suction blasting machine ARENA DF1000 for 100µm and 50µm media, and a direct pressure ARENA PF1500 for larger media. The Almen intensity was controlled with standard N and A Almen strips. For all tests, the coverage rate was 200%.

On the carburized steel sample, a double shot peening peening was performed by first peening with Zirshot HDC ZC600 at 0.25 mmA, then YZ100 at 0.10mmN.

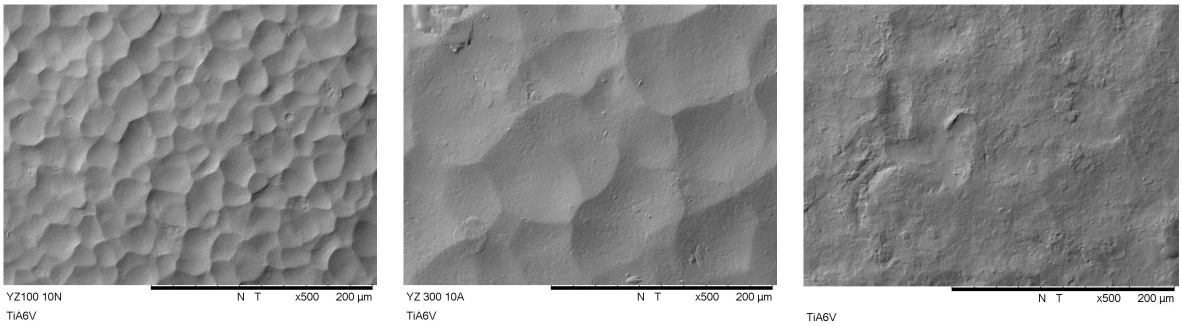
After shot peening, the surface topography and defects were assessed. Roughness were measured by a linear profilometer Mitutoyo Sj210). The surfaces were also observed by SEM Hitachi TM3030, with back-scattered electron imaging, as well as a “topographic mode” that allows to visualize the surface roughness.

X-Ray residual stress analyses were carried out with an X-Ray diffractometer X3000 (Cr Kα radiation, sin2θ method).

Experimental Results

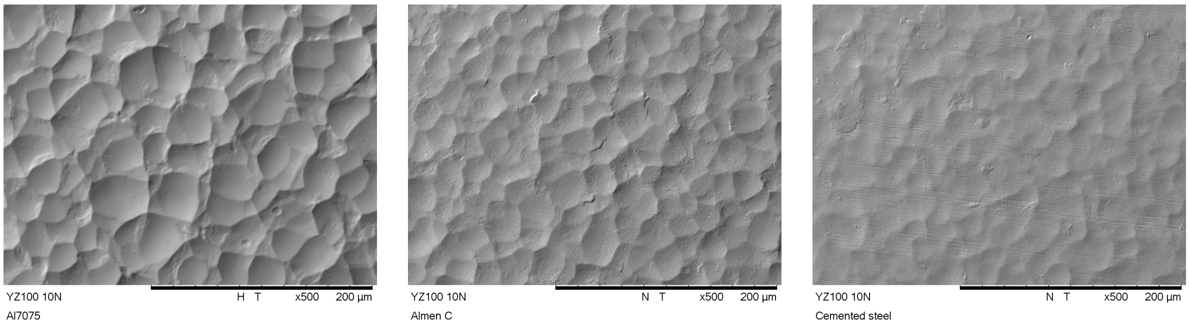
Roughness and surface

The surfaces shot peened with the high density ceramic media showed well defined craters, with depths and width depending on the media size, substrate type, and intensity. We show some SEM pictures on **Figure 1** and **Figure 2**. The typical width was about one quarter to one third of the media diameter, increasing as the target hardness decreased. The surfaces inside the craters were smoother than the ones obtained after shot peening with metallic shots, and the crater shapes better defined. As can be seen on figure **Figure 3**, the roughness increased with media size, Almen intensity, and decreasing hardness of the substrate. Even for the harder substrate (carburized steel, 800HV) and the 100µm beads, we observed a significant modification of the surface roughness: e.g. the Ra increased from 0.30µm to 0.64µm when shot peening at 0.15mm N.



YZ100 (0.10mm N) YZ300 (0.10mm A) S110 (0.10mm A)

Figure 1: Surface of TA6V samples after shot peening – SEM images in topographic mode.



Al 7075 (0.10mm N) AISI 1070 (0.10mm N) Carburized steel (0.10mm N)

Figure 2: Surface of different samples after shot peening with YZ100 at – SEM images in topographic mode.

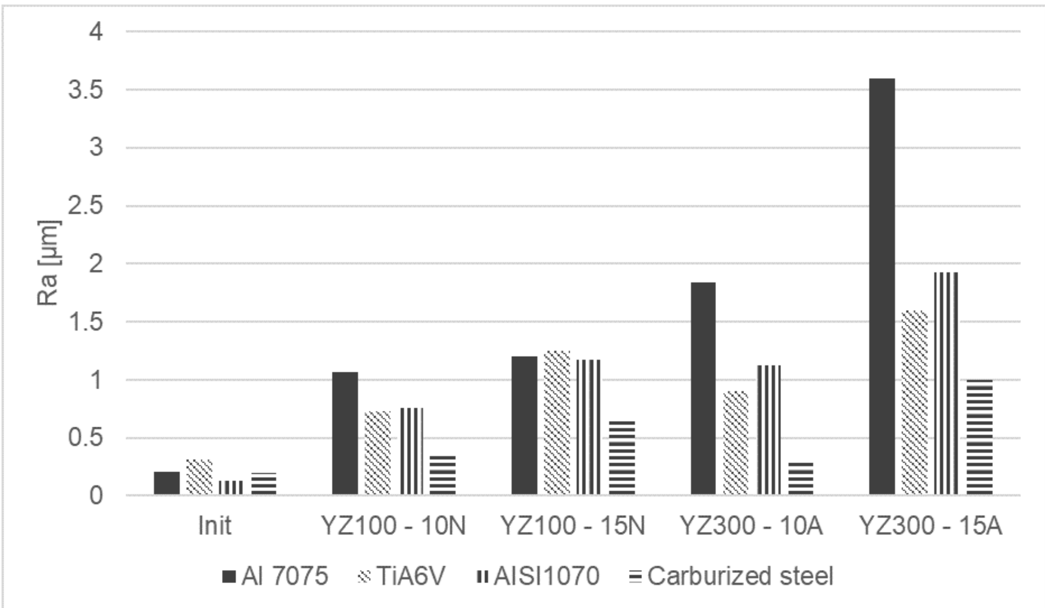


Figure 3: Ra measured before and after shot peening with the high density ceramic beads of size 100µm and 300µm.

Regarding the double shot peening test, after shot peening with ZC600 at 0.25mm A, we observed a roughness reduction after the second step, see Table 2.

	Ra [µm]	Rz [µm]
Initial surface	0.20	1.5
ZC600	0.90	4.8
ZC600 + YZ100	0.75	4.45

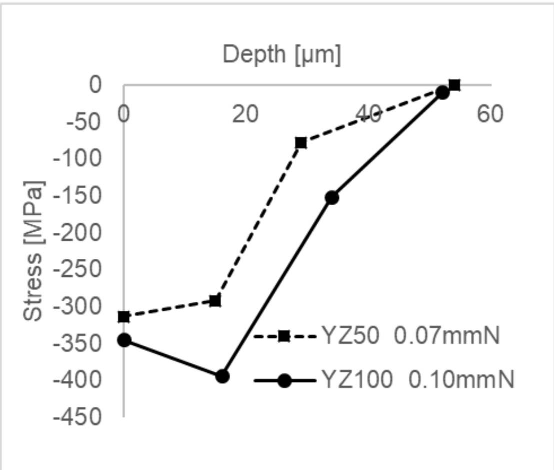
Table 2: Roughness measured on the carburized steel sample after shot peening with ZC600 at 0.25mmA, then after a second shot peening with YZ100 at 0.10mm N.

Residual stresses

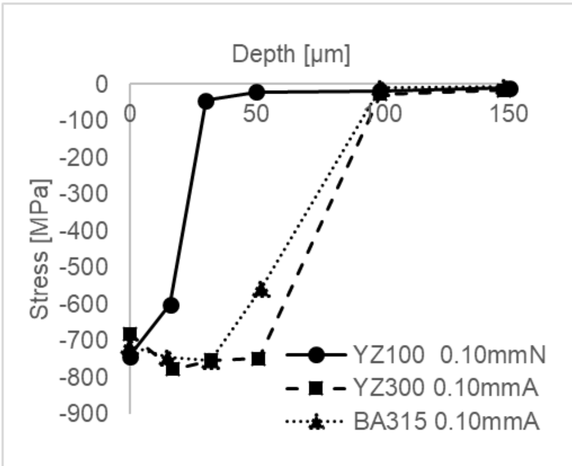
The residual stresses obtained on the various substrate of course depend strongly on the material properties. We report the measurements on aluminum and titanium samples on Figure 4.

For aluminum, with the 50µm and 100µm ceramic beads, we recover stress profiles that are similar to shot peening with fine metallic particles [9] at similar Almen intensities. The depth of the residual stress is quite shallow, from 20 to 30µm, however the maximum stress and the stress at the surface exceed 300MPa.

On titanium, the media of 300µm, either cast steel shot or ceramic, impart similar residual stress profiles. The depth of the stress profile is reduced below 40µm by using the smaller 100µm ceramic beads, while the surface stress is kept similarly at about 700MPa.



Al 7075



TA6V

Figure 4: Residual stress profiles obtained with several shot peening conditions on Aluminum 7075, and Titanium TA6V.

The residual stresses obtained on the 16MnCr5 carburized steel are reported on Figure 5. With the tested ceramic beads, the maximum stresses reach 1400MPa, which compares favorably to what can be obtained with metallic shots, but at generally at higher Almen intensity [1]. Particularly striking are the surface stresses, that are close to 1200MPa, and even 1400MPa when using double shot peening with the YZ100 as second shot peening media.

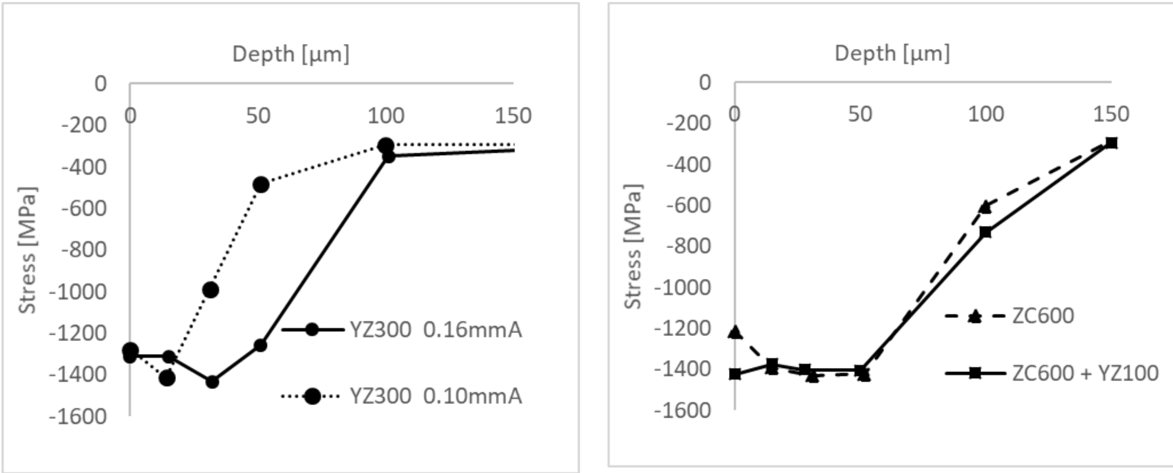


Figure 5: Residual stress profiles obtained on carburized steel.

Discussion and Conclusions

We performed a series of shot peening tests with fine and hard ceramic beads on several alloys from light soft alloys to carburized steel. Compared to all the considered alloys, the ceramic shots were significantly harder. We recovered some results that were observed in similar cases where this ratio is pronounced:

- A roughness modification that is pronounced;
- Intense residual stresses, especially at the surface.

These fine and hard ceramic media hence offer some opportunity for new treatments:

- Efficiently induce shallow but very intense residual stresses or microstructural changes – from 20 to 50µm: to improve corrosion resistance properties, treat thin parts, or use as second peening step.
- By selecting carefully, the conditions, obtain intense compressive residual stresses on very hard alloys like carburized steels, while controlling the roughness level.
- Replacing fine metallic shots to provide similar residual stresses, but with smoother surface and no prejudicial contamination e.g. on titanium alloys.

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