ENHANCEMENT OF HIGH STRENGTH STEEL ENDURANCE, APPLICATION TO AUTOMOTIVE TRANSMISSION COMPONENTS USING A NEW TYPE OF CERAMIC SHOT

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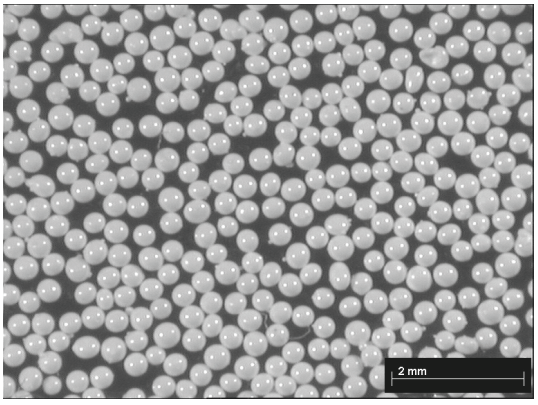
Abstract
With the first generation of ceramic shot it has been proven in industrial use that deeper residual stresses together with outstanding surface condition and very high level of compressive stress at the surface bring both higher fatigue performance and industrial benefits by reducing or even removing operations such as 2nd peening or surface conditioning [1, 2, 3].
A major European car manufacturer ([3]) has conducted tests and succeeded to improve the fatigue strength of actual automotive gears from their current production with industrial equipment using a new type of ceramic shot ([1]) by single peening operations with incredibly low use of energy, therefore significantly dropping the operating costs and enhancing the production output capability.
The car manufacturer requirements, the new ceramic shot characteristics and properties, the main features of operation design, measurement and test methods by an independent surface engineering and peening service company ([2]), the fatigue testing and results by the car manufacturer are described.

Key Words
Fatigue life, fatigue strength, high strength steel, ceramic shot, steel shot, gear, shot peening, dual shot peening, residual stress, X-ray diffraction, surface condition.

Introduction

Inside a tight budget and time frame, in order to increase the load on currently produced transmission gears, design update was not suitable and material change would bring insufficient improvement. That is why shot peening with a new type of ceramic shot, harder, tougher and denser has been tested with the target to reach high fatigue performance without changing either the design or the material and neighbour processing steps such as heat treatment.
The target is to increase the fatigue strength.
Tight cooperation between the car manufacturer, independent surface engineering and peening service company and ceramic shot manufacturer made possible having testing in a short time at development level and smoothly bringing the result to industrial use upon actual components.



Picture 1: New ceramic shot; harder, denser and tougher. Smooth surface, round shape and tight size range.

New Type of Ceramic Shot

This new ceramic shot (see picture 1) has been designed in order to fulfil the requirements of ceramic shot users to avoid or remove 2nd peening step, produce deeper residual stresses profiles whilst being stronger in use, keeping the advantages of good surface condition of the

component to be peened and high level of residual compressive stress at the surface.
Microstructure: Partly stabilized Zirconia tightly bonded in amorphous glassy phase (no crystalline Silica).
Hardness: HV 1,000. Specific gravity: 4.6.

Objective and Test Plan

The improvement of mechanical performances of carburized components, which are actual gears or shafts inside gear boxes, can be obtained through several ways:

- Change of the steel alloy
- Modification of the tooth geometry
- Introduction of the shot peening process in order to increase the residual compressive stresses.

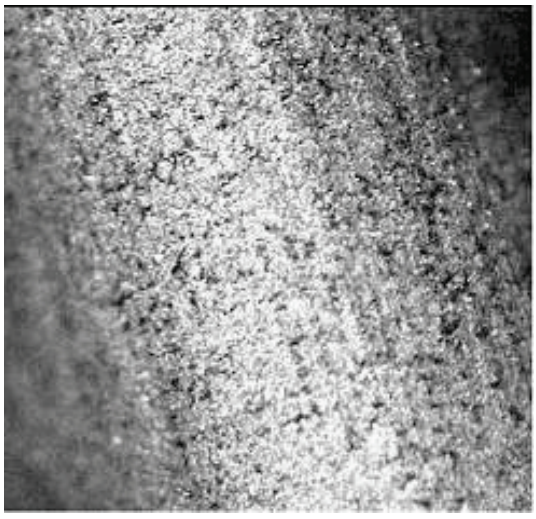
In the first case the cost increments would be very high compared with the performances benefits, while the geometry modification involves a redesign of the whole system.
The introduction of the shot peening operation, provides a remarkable improvement of the mechanical performances (approximately 25% of the endurance limit), without modifying the heat treatment parameters; therefore, in order to further improve the endurance limit, the ceramic shot peening has been tested in comparison with the basic operation made with steel shot.
The parameters of both shot peening operations are reported below (see table 1).

Parameters	Shot size (mm)	Shot Hardness (HV)	Almen Intensity (mm-A)	Coverage Rate (%)
Steel Cut Wire	0.4	640	0.35	150
Ceramic Shot	0.3 - 0.4	1'000	0.10	125

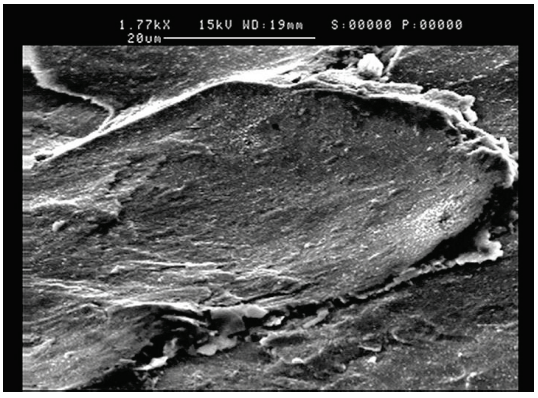
Table 1: shot peening parameters.

Measurements and Results on Fatigue Coupons and Actual Gear Components

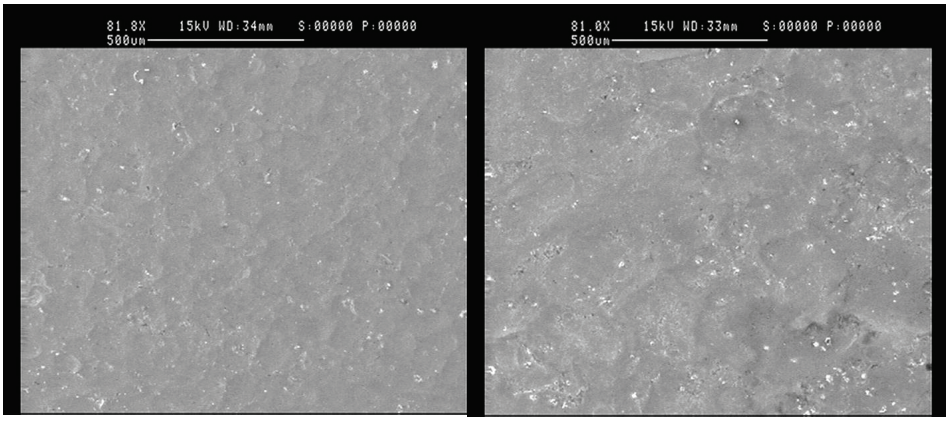
A first evaluation of the shot peening process was made on gear components, using optical microscope and SEM, in order to optimize the impact angle, Almen intensity and the coverage rate for both steel shot and ceramic shot (see pictures 2, 3 & 4).



Picture 2: Microscope picture (30 x) for coverage evaluation at tooth root on a gear component.

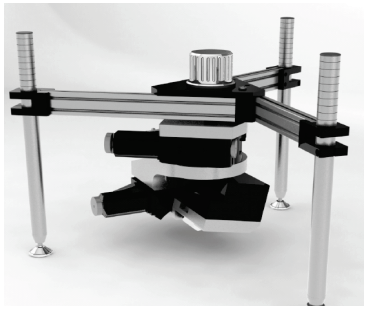


Picture 3: SEM picture of a ceramic shot indent (1,770 x)



Picture 4: SEM pictures (81 x) showing optimal surface conditions after peening a gear component with ceramic shot (left) or steel shot (right).

In a second step, the residual stress induced by shot peening has been optimized, using the X-Ray diffraction method (see picture 5).
The residual stress measurements were carried out both at the surface and in depth, after several chemical etching steps.
Chart 1 shows the residual stresses induced by using steel shot or ceramic shot. Different Almen intensities were used with the same coverage rate for ceramic shot. By using ceramic shot, the compressive stresses values are much higher at the surface than those usually obtained by using steel shot, while the affected depth depends on Almen intensity. It can be observed how the increase of intensity, going from 0.08 to 0.10 mm-A does not cause a significant change in the residual stresses profile. Therefore, 0.08 to 0.10 mm-A appears like being “optimal Almen intensity”.



Picture 5: Portable Diffractometer.

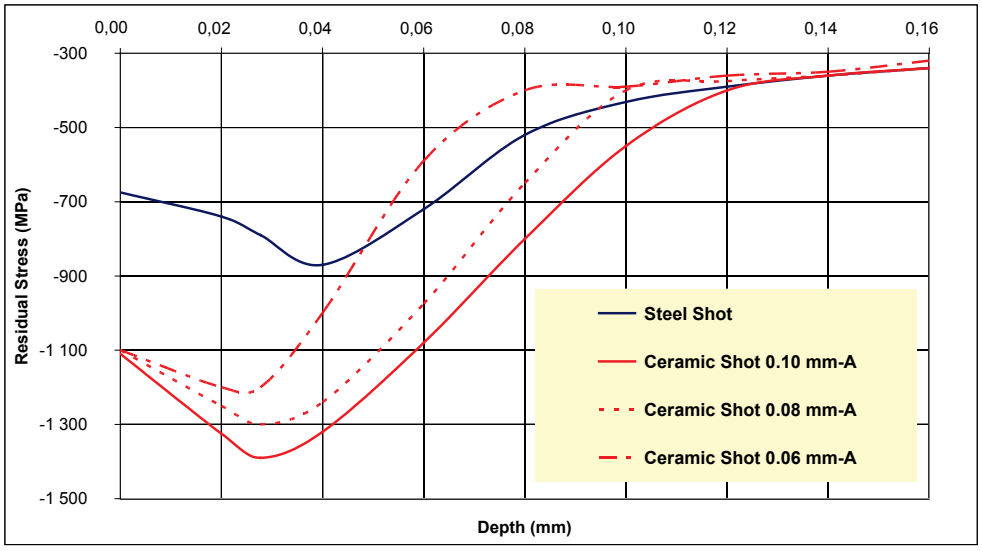


Chart 1: Typical residual stresses profiles after shot peening, measured on gear components.

Note: using specific peening parameters with the new type of ceramic shot allowed achieving a compressive residual stress peak of -1,500 MPa, with surface stresses measured up to -1,300 MPa.

As shown in chart 2, the Austenite transformation rate is also significantly improved when using ceramic shot vs. steel shot, which partly explains the higher level of compressive residual stress close to the surface.

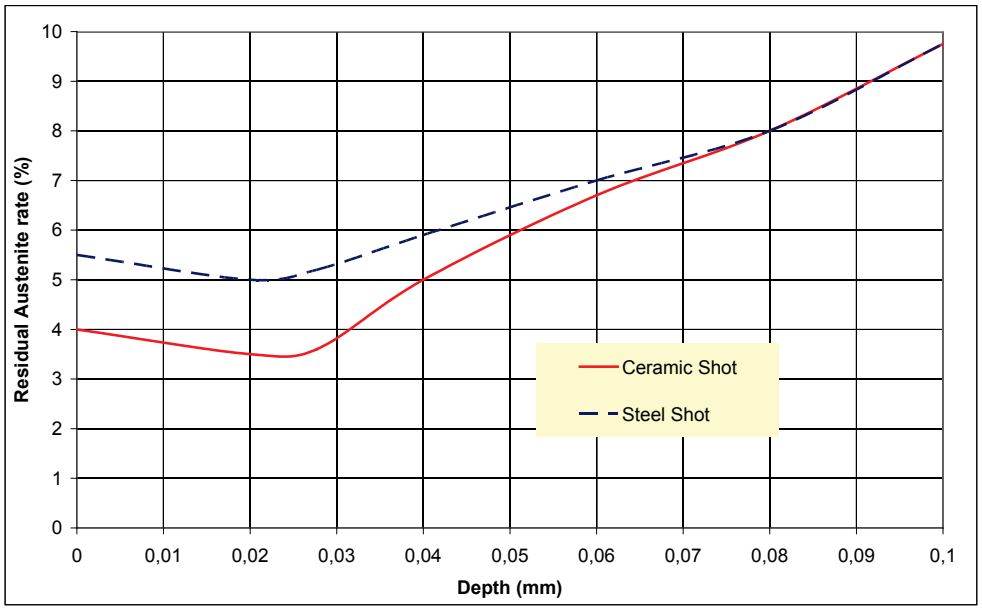
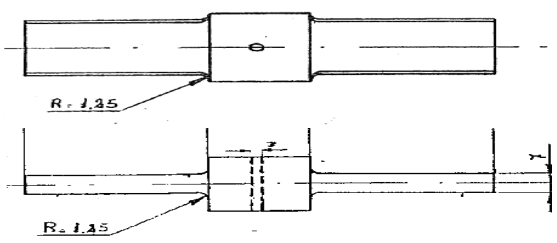
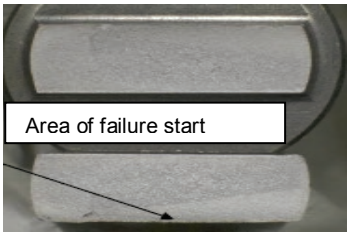


Chart 2: Typical residual Austenite rate profiles after shot peening, measured on gear components.

Fatigue Performance Results

The fatigue limit tested on standard coupons (see picture 6), with 2 x 10^6 cycles, and compared with the reference without shot peening, gives a 25% increase with the steel shot and 35% with the ceramics shot (see chart 3).





Picture 6: Fatigue coupon sketch and fracture picture

Picture 7: Fatigue test rig

Test conditions:
- 3 points bending,
- Frequency 100 Hz,
- R = 0.05 (traction/compression centred on average stress),
- Endurance limit 2x10^6,
- Stair case acquisition method (UNI 3964).

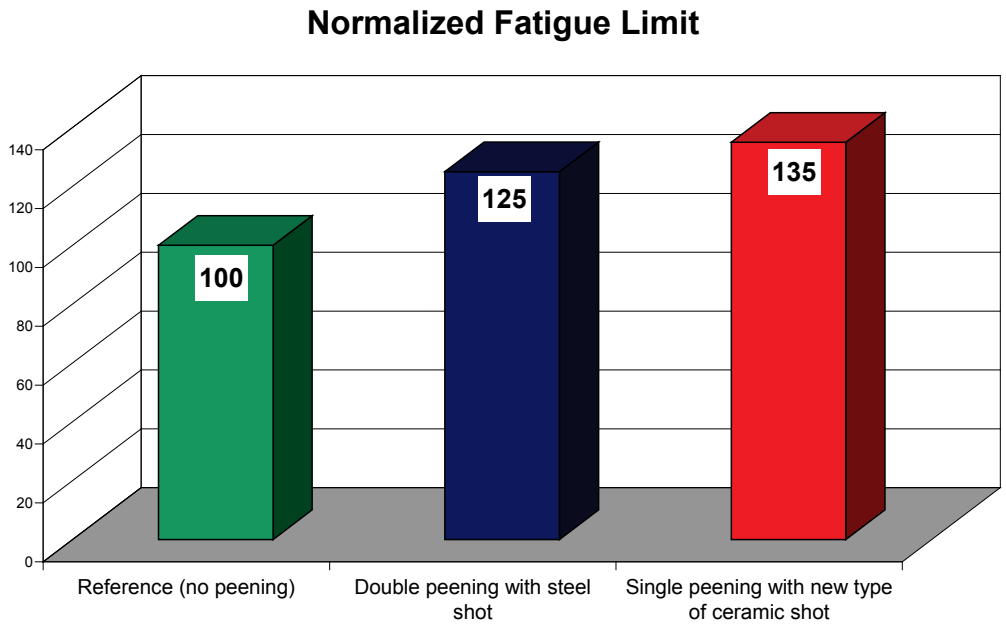


Chart 3: Fatigue limit obtained on lab. samples

Industrial Application

Usually the gear shot peening operations are carried out with nozzle machines, using cast steel shot or cut wire. The work pressure is generally high; between 4 and 7 bars. For this reason each machine requires a large air compressor. Using high energy also implies a fast wearing of the equipment, nozzles, hoses and toolings.

Shot peening carried out with ceramic shot requires a much lower energy compared with that normally used. This induces a drastic reduction of the compressed-air consumption and machine wear.

Using standard direct pressure machine, the low pressure can disturb the control functions. Practically, the valves need a minimum pressure for proper work, that in some cases may not be reached. Thanks to the light weight of ceramic shot, a Venturi gun (suction) type of machine which can easily work under low air pressure and light shot is very suitable to reach the required intensity. Of course, a sophisticated direct pressure equipment will even boost the production output capacity.

Picture 8: CNC controlled peening equipment

The experiments showed that the impingement angle with ceramic shot has a prime influence on the result vs. that commonly used with steel shot. Given the importance of this parameter, the angle was optimized by using saturation curves and set up with a CNC driven device (see picture 8).

The translation movement of the two nozzles is controlled by the CNC axis, while the gear rotation speed can be optimized by inverter: at least 10 turns during the full treatment time. This guarnties 90% shot delivery evrywhere at the component surface .

In order to understand the positive aspects of using ceramic shot for peening, the following points have to be considered:

These results are also confirmed through fatigue tests on current gears and power train components and on complete gear box systems; that allowed already to introduce the ceramic shot peening on some gear box with high torque from current production.
Previously mentioned, is the great energy saving and lower operating cost, obtained thanks to using a low air pressure.
The reduction of the environmental impact is of prime importance, due to the lower energy required and dispelled, but also to the low shot consumption, dust emission and waste disposal.

Discussion
The savings analysis is in progress: original and new costs comparison in terms of shot consumption, energy savings, equipment maintenance and process simplification by avoidance of a second peening step. This work and the amount of resulting savings are tightly related to each organization and technology status, which are all separate cases.
For further progressing it would be useful to involve the suppliers of the shot peening equipments, provided that the simple use of traditional machines does not allow drawing the full potential offered with ceramic shot and further more with the new type of ceramic shot.

Conclusion and Implications
For non disclosure reasons and limited scope of this paper, other interesting results could not be disclosed, nor deeply detailed. Nevertheless, this paper gives the key directions for industrial implementation of ceramic shot peening with a new approach.
The optimization of the process parameters provided residual stresses values like those obtained by a double shot peening, with at least the same or even significantly better improvement of the fatigue endurance.
The main components that could be subjected to this innovative process, other than gears, are springs and connecting rods, these in particular, would also benefit from a smoother surface with this process. Another interesting field is the treatment of titanium alloy components, in fact (as already demonstrated) the ceramic shot peening carried out on these materials essentially provides two advantages: reduction of the surface damages by shot peening itself (provided the low Almen intensity), and the absence of surface contamination.

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