APPLICATION OF CERAMIC SHOT FOR PEENING OF AUTOMOTIVE SUSPENSION COIL SPRINGS

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ABSTRACT

The use of ceramic shot for the improvement of high strength steel endurance is confirmed to enhance coil spring fatigue life by improving the surface condition and providing high levels of residual stress at the surface. Since the last conference in 2005 [1], a major technology development effort led by MSSC has resulted in the implementation of 2nd stage ceramic peening process in an industrial application for highly loaded suspension coil springs. Industrial benefits and a significant improvement in coil spring fatigue life have been observed. This paper reports on upgraded knowledge on ceramic peening and industrial results, including case studies on actual parts. The analysis of actual coils provides a good understanding of the benefits of ceramic peening on the material - lower surface damage and less disturbed roughness with high compressive residual stress close to the surface.

KEYWORDS

High strength steel, automotive suspension coil springs, double shot peening, ceramic shot, steel shot, fatigue life.

INTRODUCTION

Ceramic shot use began in early 80's in the aircraft industry for the shot peening of light alloys with nozzle equipments providing very good fatigue performance. This paper describes the use of ceramic media in the automotive industry on high strength steel suspension springs, working with large wheel turbine equipment, and targeting high technical performance, mass reduction, and product cost savings.

METHODS

Residual stress measurements, 3D roughness analysis, SEM inspection, and metallurgical failure analysis were conducted at Arts et Metiers Paristech Mecasurf laboratory in France. Fatigue tests on actual suspension coil springs and supporting analysis was conducted by MSSC in Milton and Detroit respectively. Modification and development of the peening equipment was conducted through collaboration between MSSC, Saint-Gobain and the Wheelabrator Group.

CERAMIC SHOT

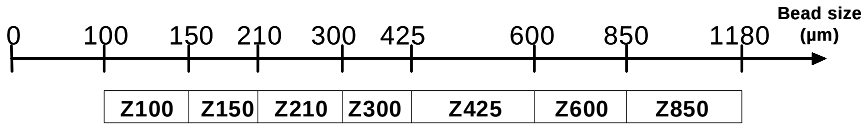
Zirshot® ceramic media for high performance applications is produced by electro fusion of oxides, providing fine and homogeneous microstructure, characterized by a crystalline Zirconia phase closely bonded within a silica glassy phase.

Zirshot® physical characteristics (typical values):

- Density: 3.85
- Bulk density: 2.3kg/l
- Micro-hardness: 700 HV_1

Pict. 1: Zirshot® Z425 (as new)

Zirshot® is highly wear and impact resistant. It is efficient in nozzle as well as wheel turbine equipments, generates no dust, no contamination therefore reduces equipment and tooling wear.



Size ranges up to Z300 are very tight. Thanks to preconditioning and shape selection, Zirshot® is showing very round shape and reduced early breakage (pict.1).

Zirshot® is particularly suitable for shot-peening applications. The main ones in automotive industries are: precision springs, coil springs, gears, power train and chassis parts…

METALLURGICAL RESULTS

- **Fatigue life improvement**

Fatigue tests carried out during quality control show significant springs fatigue life improvement. On regular production, the number of cycles to rupture can be multiplied by 10.

This performance has been obtained through an improvement process in which all the peening operations have been optimized. First of all, the first peening intensity has been 20% reduced to minimize surface damage and roughness. Then replacement of S230 second peening by Z210 ceramic peening allows combining high residual stress at the surface and good surface condition.

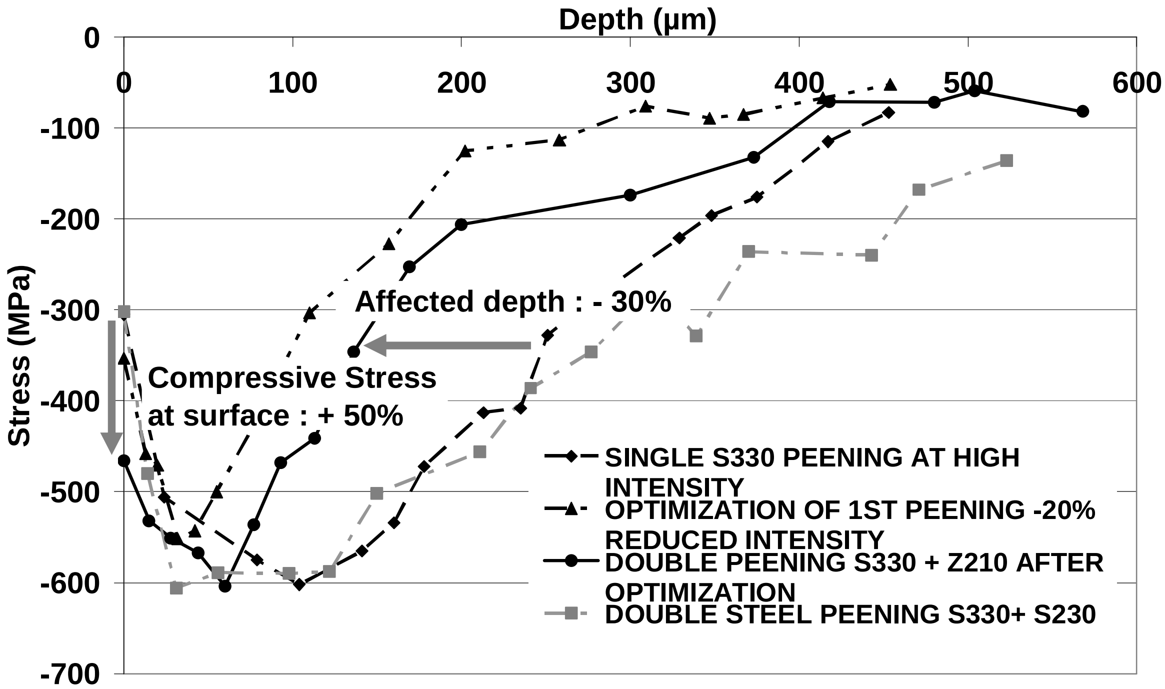


Chart 1: Residual stress profile on springs peened in different conditions

To explain the observed benefits, a range of more than 20 fatigued springs have been thoroughly analyzed. Spring samples included single steel shot peening (S330), double steel shot peening (S330+S230), and the new steel shot peening followed by ceramic shot peening (S330+Z210) process. The analysis consisted of residual stress measurement, roughness and coverage measurement, surface observation, damage analysis and thorough metallurgical investigation.

- **Residual stress effect**

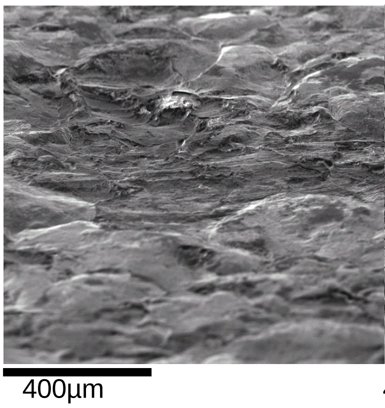
Residual stress analysis by X-rays diffraction shows that surface residual stress is higher with Z210 ceramic shot than S230 steel shot. The average surface stress on springs peened with Z210 is around -600 to -650 MPa, whereas -400 MPa is normal for steel peening, i-e a 50% increase. The depth affected by shot-peening can be modified by adjusting the almen intensity of the first shot-peening. We can conclude that surface residual stress is of great importance, along with maximum stress at depth, in considering coil spring fatigue performance.

- **Roughness effect**

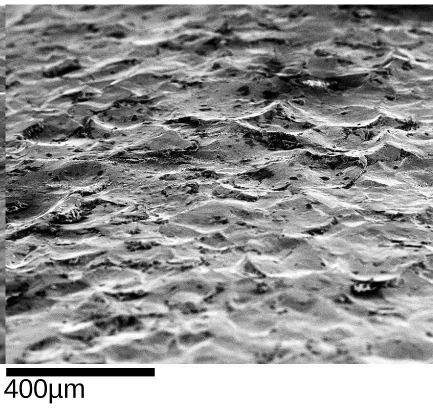
All 3D roughness parameters [2] confirm that surface condition obtained with ceramic Z210 second peening is better than that obtained with S230 second peening (Tab.1).

- **Damage reduction**

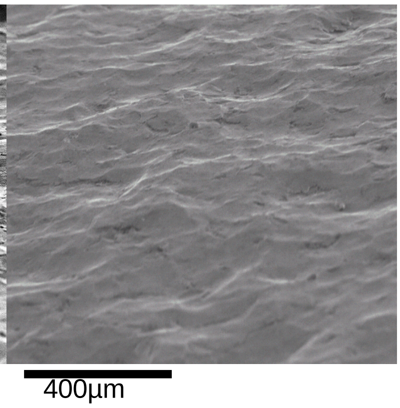
Surface damage can be evaluated by looking at the results of diffraction measurement. Evolution of integral breadths from the diffraction peaks is linked to plastic deformation and material damage; it has been observed that ceramic second peening induces less damage at the surface than steel shot peening.
The following SEM pictures confirm that trend. Picture 2 reveals deep dimples and cracks at the surface of the spring after first peening step; thanks to 2nd ceramic peening those defects are smoothened as shown on picture 4.



Pict. 2: Surface after 1st peening (S330)



Pict. 3: Surface after S330+S230 peening



Pict. 4: Surface after S330+Z210 peening

3D roughness parameters	S330 + S230	S330 + Z210	Improvement
Sa (µm)	4,5 to 5	3,8 to 4	**15%**
Sq (µm)	5,5 to 6,5	4,5 to 5	**20%**
Ssc (mm^{-1})	0,03 to 0,035	0,015 to 0,025	**50%**
Sdr (%)	3 to 3,5	1,5 to 2,5	**50%**
Sdq	0,25 to 0,27	0,19 to 0,20	**30%**
Surface residual stress (MPa)	-400 MPa	-600 MPa	**50%**

Tab. 1: Roughness and surface residual stress of peened spring.

INDUSTRIAL APPLICATION OF CERAMIC PEENING

- **Peening Process**

The peening technology employed in this ceramic media peening process for peening of automotive suspension is described and protected in the author's patent filing. In short, a 2-stage peening system is used in which an initial peening with steel media at an elevated temperature is followed by subsequent peening with ceramic media.

This peening process results in overlaid residual stress curves and other complimentary metallurgical effects that support a significant increase in product fatigue life.

- **Peening Machine**

The industrial implementation at MSSC began with a four wheel continuous peening machine designed to throw steel shot and capable of handling up to 900 coil springs per hour.

Conversion of the machine to use the ceramic media required optimization of several of the machine's key subsystems. In particular the media handling and cleaning system, the storage and shot feeding mechanism.

In addition, significant time and effort was put into the development of a customized blast wheel to enhance the ceramic performance.

The operating results are repeatable and the machinery has demonstrated high robustness with no significant operational equipment problem.

To date the modified peening equipment has performed very well.

- **Ceramic Media Management**

As the ceramic media is physically much smaller and lighter than steel shot, the dust separation and collection systems was changed to handle the lighter material. This included the addition of cyclones and custom ducting. The shot feeding mechanism was modified to work with the non-metallic media, and an orifice methodology was used to control shot flow. The blast wheels themselves were upgraded to a proprietary design that is more suited to throwing the light media. Other changes have been implemented as the process technology was developed.

- **Peening Process Control**

The shop controls implemented to support the ceramic peening process are similar to those used in steel peening of vehicle springs. This includes regular almen and coverage checks, media sampling, and automatic monitoring of the blast wheels.

The operation is very stable and the process quality checks have shown that the process and equipment do not migrate from expectations.

INDUSTRIAL FATIGUE RESULTS ON AUTOMOTIVE COIL SPRINGS

Coil spring fatigue life has been demonstrated to increase from that achieved when processed with 2-stage peening with steel shot only. In a variety of case studies, fatigue life performance has been shown to increase from a low of 50%, to a high of over 500% of the life achieved with steel peening.

Additionally, following recent work fatigue life scatter within a sample set has been found to be reduced from that which was observed with steel shot peening only.

- **Fatigue Life Comparison**

The following case results have been taken from actual automotive coil development and testing work completed at MSSC. In each example, the 'Steel Media' data represent a 2-stage steel peening process, and 'Ceramic Media' refers to coil springs processed by the new proprietary 2-stage ceramic peening process.

Case 1 - Normal Stress Design

Product 1	**2nd Stage - Steel Media**		**2nd Stage - Ceramic Media**	
	Fatigue Cycles	**Result**	**Fatigue Cycles**	**Result**
Alloy	204,700	Susp.	258,000	Susp.
9254	131,000	Fract.	258,000	Susp.
	172,700	Fract.	275,000	Susp.
Bar	167,000	Fract.	275,000	Susp.
0.625"x118.5"	192,000	Susp.	375,000	Susp.
	125,000	Fract.	375,000	
Avg. Cycles	165,400		302,600	
B10 =	118,500		n/a	

Case 2 - High Stress Design

Product 2	**2nd Stage - Steel Media**		**2nd Stage - Ceramic Media**	
	Fatigue Cycles	**Result**	**Fatigue Cycles**	**Result**
Alloy	91,890	Fract.	135,732	Fract.
StelRMM	88,589	Fract.	147,530	Fract.
	85,543	Fract.	143,046	Fract.
Bar	94,505	Fract.	171,172	Fract.
	83,000	Fract.	218,668	Fract.
	96,112	Susp.	187,712	Susp.
Avg. Cycles	89,389		167,310	
B10 =	81,933		123,804	

Case 3 - Very High Stress Design

Product 3	**2nd Stage - Steel Media**		**2nd Stage - Ceramic Media**	
	Fatigue Cycles	**Result**	**Fatigue Cycles**	**Result**
Alloy	116,800	Fract.	298,000	Fract.
HDS-12	253,300	Fract.	298,000	Susp.
	200,900	Fract.	196,500	Fract.
Bar	95,900	Fract.	196,500	Susp.
0.457"x87.5"	123,400	Fract.	350,000	Fract.
	178,200	Susp.	350,000	Susp.
Avg. Cycles	161,400		281,500	
B10 =	83,200		207,600	

As seen in the results tabulated above, the use of the developed 2-stage ceramic peening process can greatly increase the fatigue life of automotive coil springs.

Case 4 – Reduced Mass Design

The following table documents the results of reduced mass design work for a highly stressed double pigtailed coil spring. The fatigue life achieved with the original design (bar size) using 2-stage steel peening is compared to the reduced mass design peened with the 2-stage ceramic process.

Product 3	**2nd Stage - Steel Media**		**2nd Stage - Ceramic Media**	
	Fatigue Cycles	**Result**	**Fatigue Cycles**	**Result**
Bar	0.527"x72.5"	---	0.510"x69.5"	10.4% mass red'n
	146,000	Susp.	382,000	Fract.
Alloy	146,000	Fract.	675,800	Susp.
92V45	177,000	Susp.	675,800	Fract.
	177,000	Fract.	445,000	Susp.
	198,000	Susp.	445,000	Fract.
	198,000	Susp.		
Avg. Cycles	173,600		437,266	
B10 =	143,624		333,764	

The benefits of the new process are obvious - MSSC is able to improve coil spring designs such that both significant mass reductions and improved fatigue life are achievable in the same package. This technology development results in both mass and cost savings to customers.

CONCLUSIONS and IMPLICATIONS

The work described in this paper provided a significant increase in fatigue lifetime of automotive suspension coil springs. This outright improvement has been used industrially to integrate shot peening benefits into the early steps of suspension systems design supporting automotive OEM need for mass and cost reduction.

ACKNOWLEDGEMENTS

WHEELABRATOR-GROUP in North America, for their participation in peening equipment development trials and subsequent modifications.

ARVINMERITOR Development Laboratory and test facilities in Detroit, Michigan.

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