SUMEBore – thermally sprayed protective coatings for cylinder liner surfaces

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Summary

Rising fuel prices and more stringent requirements in the field of the vehicle emissions such as nitrogen oxides, particulate matter and carbon dioxide are increasing the pressure on the engine manufacturers to utilise technologies which contribute to a reduction in these emissions. As a result, interest in cylinder surface coatings has risen considerably in the last three years, also in the SUME*Bore*® coating solution from Sulzer Metco.

SUME*Bore* coatings are applied by a powder-based air plasma spraying (APS) process. The APS method is very flexible and can also process materials to which wire-based methods do not have any access, particularly metal matrix composites and pure ceramics. The compositions can be tailored to the specific challenges in an engine, e.g. excessive abrasive wear, scuffing, corrosion caused by adulterated fuel, etc. Over the past four to five years liner surfaces from trucks, diesel locomotives, marine and gas engines, for power generation and gas compression have been coated with SUME*Bore* materials. These engines have been tested successfully. Most of the tested engines achieved significant reductions in lube oil consumption, sometimes in excess of 50%, reduced fuel consumption, very low wear rates and corrosion resistance on the liner surfaces.

The coating solution of Sulzer Metco has been commercialized in various markets; it has proven to be suitable for mass production on both new engine blocks and liners, and for repair of worn-out parts. Such coatings will continue to play an important role when it comes to reductions of emissions from internal combustion engines. Sulzer Metco offers both a coating service to supply coated parts to customers or fully customized equipment and materials to apply coatings at the customer's sites around the globe.

1. Introduction

As early as at the start of the nineties, Sulzer Metco began to develop equipment with rotating APS torches in order to coat cylinder surfaces in both aluminium and cast iron engine blocks. Today, this so-called RotaPlasma® equipment is utilised by various customers of Sulzer Metco to coat cylinder bores in engine blocks. For liner type engines the same plasma torches can be used for the coating application but with the liner rotating, instead of a rotating plasma torch. Figure 1 shows both an aluminum 4-cylinder block ready to be coated and coated truck liners.

Over many years the installation technology was refined and new materials which are tailored to the various liner surfaces to achieve low friction, high wear, corrosion resistance and low oil consumption (to name just a few) were developed. Together with NAGEL in Nürtingen and SUNNEN in St. Louis, honing of the coatings were optimised in order to bring out the advantages of the coating porosity. The progress with regard to the development of the process and the materials has been documented in a number of publications [1-25]. Today, the cylinder ID surface coating from Sulzer Metco is offered on the market as an overall solution under the name of SUME*Bore*®. Sulzer Metco together with partners offers a turn key solution for industrialisation of the SUME*Bore* coating of cylinder liner surfaces.

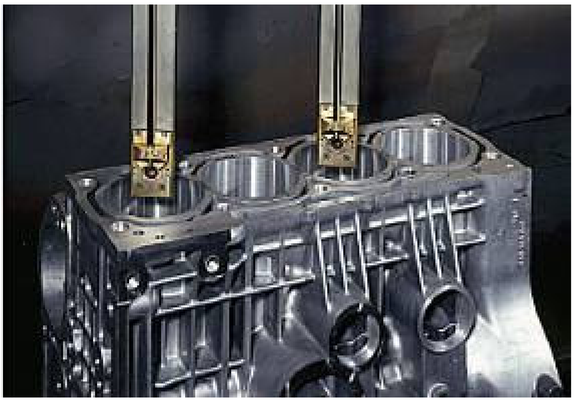


Figure 1: Aluminum engine block coated with rotating plasma torch

Cylinder liners from a truck engine, coated with rotating liner

2. Process description

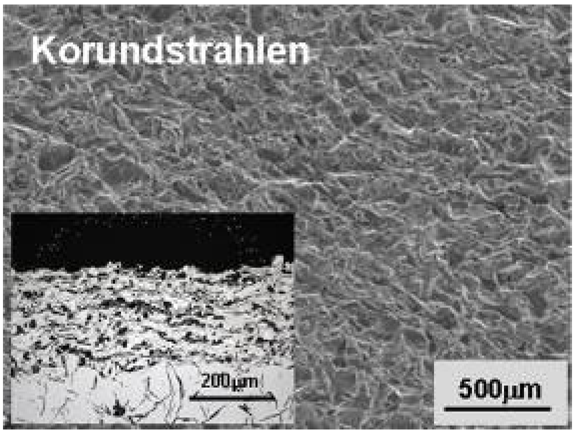
The whole process of the cylinder surface coating is portrayed schematically in Figure 2 on an aluminum engine block (without washing / cleaning). The process flow is identical for coating of liners that are typically made of cast iron.

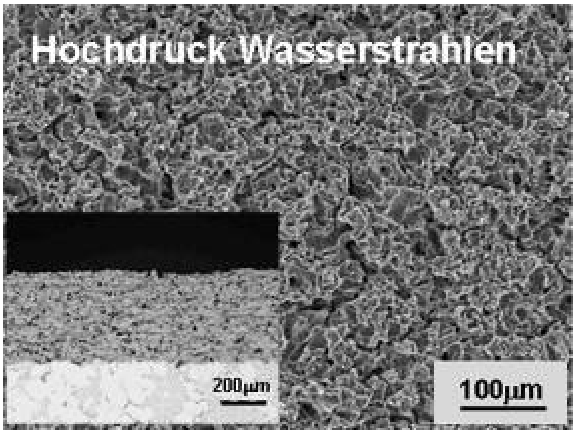
Figure 2: Schematic representation of the SUME*Bore* process (from left to right, including honing)

2.1 Preparation and surface activation

Before the coating application the bore diameter has to be pre-machined to oversize to accommodate the coating. The oversize is determined by the intended coating thickness after honing. This pre-machining can be carried out by means of line boring, single point drilling, honing, etc. A roughness $R_a < 4\mu m$ is required after pre-machining. Thereafter the part has to be thoroughly cleaned / washed, to remove any oil and grease from the surface. The min. surface tension after cleaning and drying is ca. 36mN/m, in the area where the coating will be applied.

The next step in the process is the surface activation. It consists of a surface roughening to increase the surface area and produce a structure which facilitates the mechanical interlocking of the coating with the substrate and guarantees the adhesion of the coating. In principle there are a number of processes available for the activation of the surface. Activated surfaces generated with the most commonly used activation processes are shown in Figure 3.





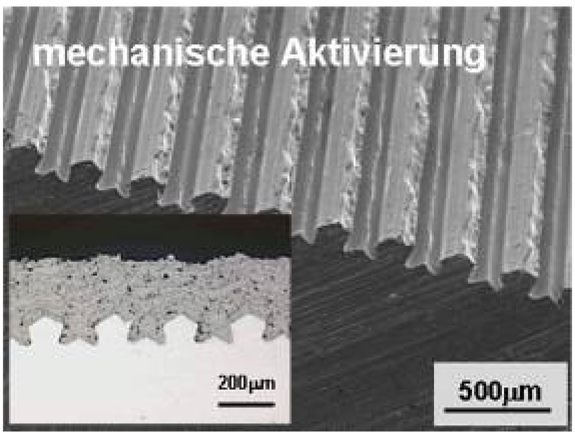


Figure 3: activated (roughened) surfaces from three different processes. Small pictures: transverse profile of plasma coatings on activated surfaces ("as sprayed")

Top left: grit blasting (with Al_2O_3), top right: high pressure water jet, bottom left: mechanical activation (machining) with the profile of the TU Braunschweig [26]

Grit blasting with Al_2O_3 is suitable for the activation of all materials and is most flexible with regard to geometrical constraints, e.g. at the bottom of the bores in engine blocks (pulsation holes, honing allowance, bearing block, etc). Grit blasting is the most frequently used activation process. It is utilized in all the large-scale series production installations used today for the application of thermally sprayed cylinder surfaces, both in engine blocks and liners. After grit blasting the activated surface is cleaned with pressurized air, before the coating is applied.

High pressure water jet activation (without abrasive particles in the water) works well on aluminum but not on cast iron. In principle the mechanical activation (machining a profile) works on both aluminum and cast iron, however, the tool wear during the activation of cast iron is excessively high, which does not allow an economic process [26].

2.2 APS coating process and materials

As indicated above, the APS coatings are applied either with a rotating plasma torch (engine blocks) or if the parts are rotationally symmetrical (liners) they can easily be rotated and the plasma torch will only move up and down in Z-axis during the coating application. Different torches are used depending on the size of the bores. Below a diameter of Ø150mm, this would generally be the F210 gun, while for larger bores which are typically used in both 2-stroke and 4-stroke medium speed diesel engines and gas compressors the best choice is the iPro90. Typically powder feed rates are in the range of approximately 250g/min. The two torches can bee seen in operation in a Ø81mm bore of an aluminum engine block and in a medium speed diesel liner with Ø250mm in Figure 4.

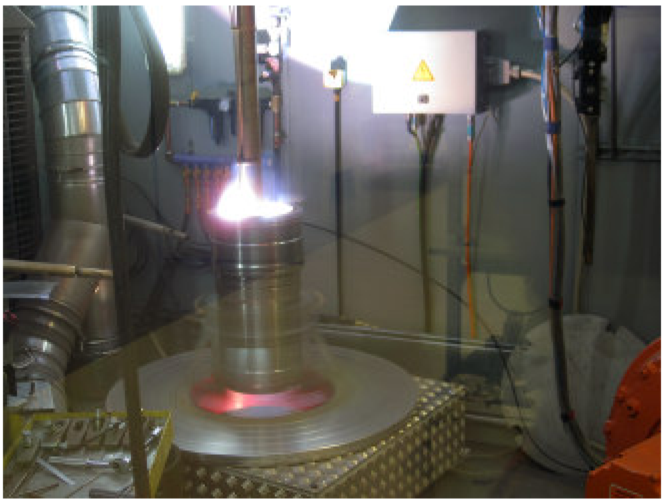


Figure 4: F210 plasma torch in a Ø81mm bore of an aluminum engine block (left) and the iPro90 torch in a rotating Ø250mm medium speed diesel engine liner

Bores with diameters above 500mm would be coated with the TriplexPro plasma torch, with powder feed rates of up to 500g/min.

All of these plasma torches use powder as a feedstock and they are standard products of Sulzer Metco. The advantages of using powder instead of wire are obvious. The diversity of materials is almost unlimited and the compositions extend from low-alloyed carbon steel through metal matrix composites (MMCs) – a mixture of metal and ceramic – right up to pure ceramics. In addition the powder based approach makes it easy to blend in solid lubricants such a MoS_2, WS_2, ZnO and others. In principle all powders suited for plasma spraying can be processed. The table below shows a few typical SUME*Bore* powders that are used by Sulzer Metco (coating service) or its customers today.

Standard SUMEBore materials (powders) for heavy-duty diesel engine applications

Designation / composition	C	Mn	Cr	Mo	Ni	Fe	others
Metco F2056	>1	1 – 2	1 – 2	-	-	bal.	Al_2O_3/ZrO_2
Metco F2071	< 0.5	< 1	> 12	> 2	-	bal.	Al_2O_3/ZrO_2
Metco F2220	-	< 0.5	> 28	> 4	< 0.3	bal.	Al_2O_3/ZrO_2

MMCs have proven to be the best option for heavy-duty diesel engines (trucks, marine engines, power generation, etc.). The matrix can be tailored to the application, and if necessary it can be corrosion-resistant. The abrasive wear is taken care of by the addition of a "soft" ceramic, which can added in different amounts, typically > 30 wt-%.

A typical coating thickness after final machining (honing) is in the range of 120µm for passenger and high performance car applications, for heavy-duty diesel engine applications the target coating thickness is around 150µm. Including the honing allowance the coating thickness in the "as sprayed" condition is around 230µm and ca. 280µm, respectively. Typical values for the surface roughness in the "as sprayed" condition are R_z of ca. 50µm and R_{max} of 60µm, which is very smooth, compared to wire sprayed surfaces.

SUME*Bore* coating technology can also be applied for the remanufacturing of worn-out parts. If necessary a coating thickness of up to 1mm can be achieved, depending on the bore size and the coating material. This is an important feature of the coating solution, as it permits remanufacturing options formerly not available, for example bringing cylinder bores back to original size. This is attractive for many engine types, because it requires only a single size of piston, single size of cylinder head sealing device and simplifies the logistics significantly.

2.3 Final machining (honing)

The final machining of the plasma coating is a very important step which is carried out by honing with diamond ledges. The final surface has a mirror finish, without a plateau honing pattern. Over the past few years the recommended specification for the honed, plasma coated surface has been refined, based on engine tests with measurements of reduction of lube oil and fuel oil consumption. For heavy-duty diesel liner coatings the following specification is aimed at:

- R_a:0.15 – 0.35 µm
- R_z:< 5 µm
- R_k:< 0.3 µm
- R_{pk}: 0.07 – 0.16 µm
- R_{vk}: 0.5 – 2.0 µm

A honed plasma surface can be seen in Figure 5 in the scanning electron microscope (SEM). It reveals one of the main characteristics of this type of coatings - the porosity – which retains the oil in the surface and which is the reason why the surface can be honed to a mirror finish and would not scuff, like a polished cast iron bore. It is important to do the honing in such a way that the pores are properly opened and that they do not contain any debris from the honing process. Figure 6 shows the mirror finished surface of a Ø200mm cylinder liner.

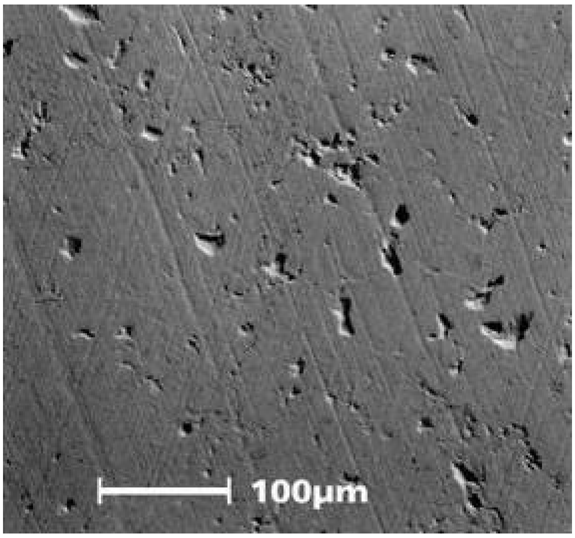


Figure 5: SEM picture of honed surface with porosity for oil retention

Figure 6: honed Ø200mm SUME*Bore* coated cylinder liner with mirror finished surface

3. Applications and industrialisation

For a long time, Volkswagen was Sulzer Metco's only customer to utilise the APS cylinder surface coatings in large-series production. Over the past 6 years VW has coated close to 3 million bores with the technology from Sulzer Metco. However, other customers have been added recently. One Japanese customer purchased customized SUME*Bore* equipment and is coating a new V6 aluminum outboard engine. In addition the first installation for the large-series coating of truck liners went into production at SCANIA at the end of 2010. An overview and some details of the installation are shown in Figure 7. The equipment is fully automated and designed for a 3-shift operation.

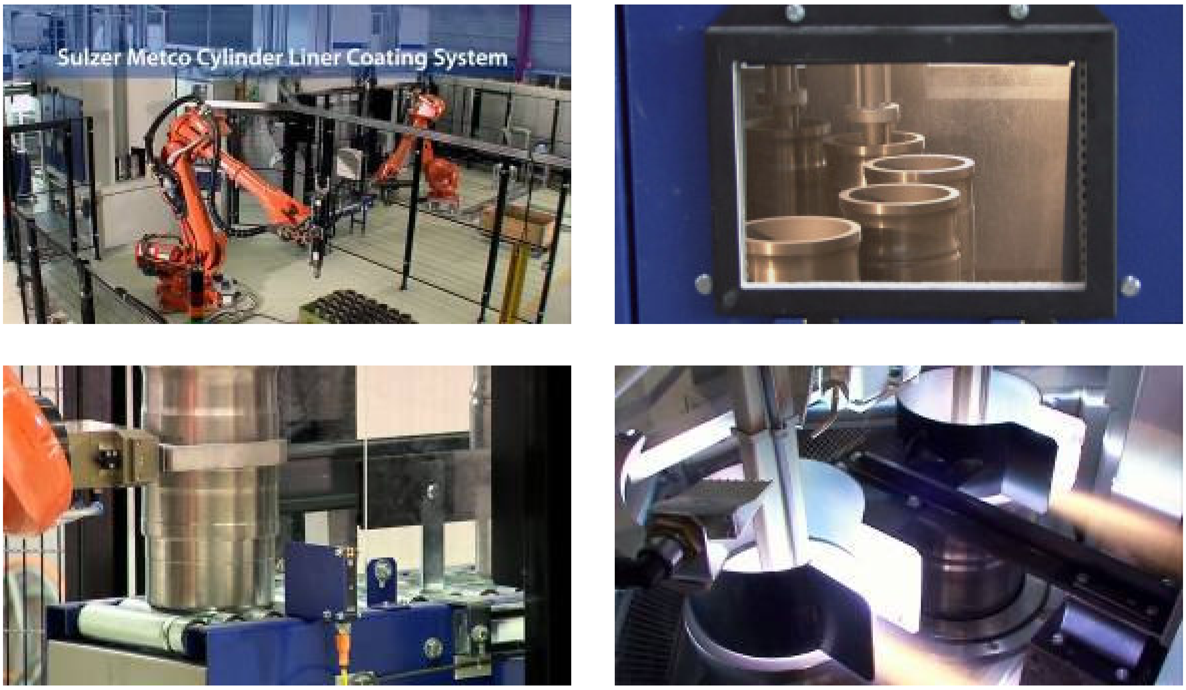


Figure 7: upper left: overview of the truck liner coating installation for large series production, upper right: grit blasting of cylinder ID surfaces for activation, lower left: transfer of liner to the plasma coating booth, lower right: plasma coating application with 2 torches

Large prototype liners from Ø150mm up to Ø380mm were coated by Sulzer Metco over the past two years and went into engine tests at various customers. Most of these tests have confirmed the potential of the SUME*Bore* coatings, with regard to reduction of lube oil and fuel oil consumption, abrasive wear, corrosion resistance and low friction. Sulzer Metco operates two SUME*Bore* coating shops, one in Wohlen (Switzerland) and one in Westbury (USA). Both shops offer coating service for small-scale series production and for prototype coating development / application for engine tests and can support the ramp-up of a large scale-series production for new SUME*Bore* customers. Pictures from both shops and some typical parts that are coated are shown in Figure 8.

Figure 8: upper left: SUMEBore coating shop in Wohlen with a small series aluminum 4-cylinder block, upper right: SUME*Bore* shop in Westbury with a 6-cylinder cast iron block for remanufacturing, lower row: 4-stroke and 2-stroke locomotive engine liner and liners from an industrial gas engine

4. Conclusions and outlook

From the evidence presented elsewhere in this narrative it can be seen that SUME*Bore* is both a versatile and robust coating system. It has emerged, especially over the past 4 years, as a leading edge choice of Original Equipment Manufacturers (OEM's) for both new and re-manufactured liners and cylinder blocks. As a proven and robust product capable of withstanding the rigors of high speed and highly automated industrial production processes SUME*Bore* has become a preferred solution for many engine professionals. A broad base of materials in the SUME*Bore* "Tool Box" extends the solution capability of this system into all types of reciprocating engines no matter what the application or design parameters of the engine are. What does a Formula 1 engine and a medium speed 300mm bore marine diesel have in common when SUME*Bore* is applied to them? Quite a lot:

- Both benefit from reduced cylinder friction, one to produce more power the other to reduce fuel consumption.
- Both benefit from reduced lube oil consumption one because it means a reduced oil capacity and therefore overall engine weight and the other for reductions in operating costs.
- Both engines benefit from a reduction in bore wear.

These common themes are further enhanced by the reduced need to develop application specific solutions for engine exhaust and other mission and regulatory critical concerns. Corrosion resistance for EGR engines operating on high sulphur fuels, reduced LOC, reduced FOC, reduced exhaust PM and enhanced bore life all in one technological and proven package represents a considerable cost saving in R&D against developing specific solutions for each of the above referred items. As a licensed and IP protected solution SUME*Bore* presents OEM's with significant advantages in the service and support aftermarket via a technology that is not commonly available to "Will Fit" parts manufacturers. This of course has implications on the margins generated in the after sales arena.

What of the future? Sulzer Metco maintains an intense but low key focus on the competitive Auto Sports section of the engine business. In comparison to production based design high level auto sport engine engineering is a "high risk" environment where "out of the box" thinking and creative solutions are actively encouraged. Development budgets are now mere shadows of their mid 90's glory days, none the less money is available for developments that would struggle for funding in commercial environments. Within this genre SUME*Bore* actively develops new materials and process parameters. Currently several new materials are being used in active high level competition such as Formula 1, NASCAR, Le Mans and DTM to mention just a few. Engine types cover both spark ignited and compression ignition and materials under development include carbide based, pure ceramic as well as a ferrous and titanium based material. These environments are highly stressed, jacket water temperatures can and do regularly exceed 150°C, very high BMEP in competition diesels, mean piston speeds exceeding 27m/sec., and rod / stroke ratios in the range of as low as 1.6 to as high as 2.6 to 1. This is a hostile environment and an ideal environment for the introduction of a new or modified coating.

Today Sulzer Metco routinely applies virtually identical coatings and with the same technology as those applied end of the 1990's to Cosworth V10 Formula 1 engines. Essentially Formula 1 technology has migrated down to common automotive, industrial and medium speed diesels engines in common use today.

5. References

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