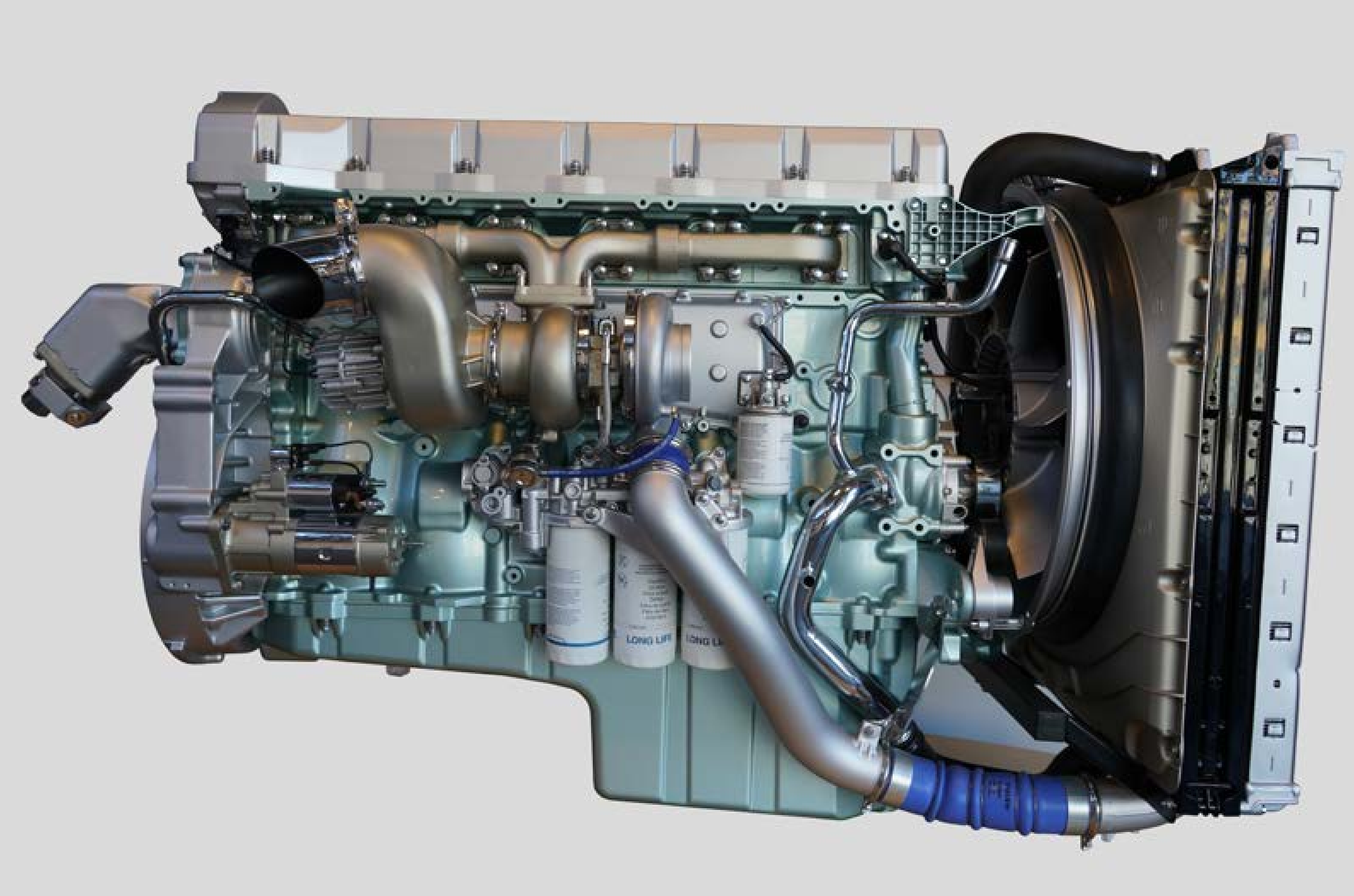

COATING FOR IMPROVED INNER CLEANLINESS

FOSECO

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The following article is the result of a long-lasting cooperation between two companies which have committed during times when the internet, social media and smart phones were in their infancy, to commonly develop future visions.

One company located in Skovde, Sweden has developed a new metal pouring process (FPC – Future Process for Casting) and they run their new foundry based on this technology.

The subject presented in this article was commonly developed over the last 20 years. The coating technology discussed delivers multiple improvements to inner cleanliness or in other words reduces the quantity of remaining particles in inner critical channels. Obviously, this improves engine lifetime and additionally reduces downtime due to, for example the exchange of oil or coolant liquids – a still hot current subject.

Particle adherence using conventional coating

Very clean internal surfaces even in narrow channels

INTRODUCTION

Nov. 16, 2017 (WASHINGTON)
The following is a statement from Allen Schaeffer, Executive Director of the Diesel Technology Forum. [1]

"Diesel is the most energy efficient internal combustion engine. It has achieved dominance as the technology of choice in the trucking industry over many decades and challenges from many other fuel types. Still, today, diesel offers a unique combination of unmatched features: proven fuel efficiency, economical operation, power, reliability, durability, availability, easy access to fueling and service facilities, and now near-zero emissions performance."
"We all benefit from a more efficient freight system. Fuel and powertrain choices are one part of that. The greatest opportunity for efficiency gains, fuel savings, lower greenhouse gas emissions and cleaner air – now – is to get more truckers into the newest generation of more fuel efficient and near-zero emissions clean diesel technology, as rapidly as possible."

Legal requirements
"The legal requirements for diesel engines have been tightened several times. Diesel engines are used in various types of vehicles, for various types of traffic, and with varying loads. To be able to measure emissions in a comparable way, they are measured in relation to the work performed by an engine and the units used are grams per kilowatt-hour. For certification, a well defined fuel is used, very similar to standard fuel but with closer tolerances."[2] (Table 1).

Euro 7 Emission Norms – 2020 CO_2 Goals:
"Euro 7 emission norms are expected to be implemented in 2020, with a CO_2 emission target of 95 grams per kilometer. The Euro 6 CO_2 target of 130 gm/km will then have to be reduced by 27% with a slew of technology adoptions and enhancements."[4] This applies for cars and vans, but has not been defined for trucks, yet.

The influence of a coating manufacturer to the final engine life and performance by coating selection applied seems to be very limited in this context and even more if we think about an impact on performance of the engine itself. In the past all a coating could do was to ensure a defect free component.

Today the influence of a coating applied at a thickness of about 3 human hairs goes way beyond the actual cast component. It can modify the metal matrix and the performance of the final engine.

Let's ask the question: What determines a powerful and environmentally friendly engine?

Legal requirements and limit values

	Law from	NOx g/kWh	PM g/kWh	HC g/kWh	CO g/kWh
R49.00	1982	18	-	3.50	14
Euro 0	1990	14.4	-	2.40	11.2
Euro 1	1993	8.0	0.36	1.10	4.5
Euro 2	1996	7.0	0.15	1.10	4.0
Euro 3	2001	5.0	0.10	0.66	2.1
Euro 4	2006	3.5	0.02	0.46	1.5
Euro 5	2009	2.0	0.02	0.46	1.5
Euro 6	2013	0.4	0.01	0.13	1.5

Table 1. EU emission standards for heavy-duty diesel engines: Steady-state testing [3]

COATING FOR IMPROVED INNER CLEANLINESS

The frequency of modern engines regarding service intervals is becoming longer and longer. In effect the mileage until an oil change is required has increased by 3 times on average from 5,000km to now ca 15,000km sometimes even 30,000km. In addition the technical demands on the oil itself have become more severe.

But what if this modern engine runs not on ordinary streets, motorways and on shore, but off shore on the sea where the next fuel and service station might be some considerable sea miles away. In this case the engine needs to be the most reliable part of the total machinery. Volvo has a marine department called Penta, which designs and manufactures complete engines for not just high performance power boats (http://www.frauscherboats.com/), but also for sea rescue boats, towboats and others. In order to extend the competitiveness of this department and to raise the engine performance ahead of all competition new ways had to be developed which involve all different steps in cast component manufacturing.

What was considered in the past to be engine oil performance has now grown into a new dimension: Inner Cleanliness.

Coatings are usually applied on sand cores that build the inner geometries and complexities of an engine. In particular, thin sections in the engine block or cylinder head are prone to defects and also sand adherence due to shot blast kinetic energy loss.

If a coating could contribute to the inner cleanliness of a cylinder-block or head all the following manufacturing steps from heat treatment up to final machining would become easier and more efficient and the economic value would increase.

Figure 1. Contaminated coolant

Figure 2. Residues in oil

Figure 3. Euro 6 Diesel Engine

The investigation of this "inner cleanliness" concept is not simple because a common industrial standard is not yet defined. All engine manufacturers use internal standards, hence there is a wide spread of OEM demands. Also, a method for testing did not exist, hence the Volvo/Foseco cooperation had to establish a reproducible and repeatable way of evaluating remaining particles inside a casting.

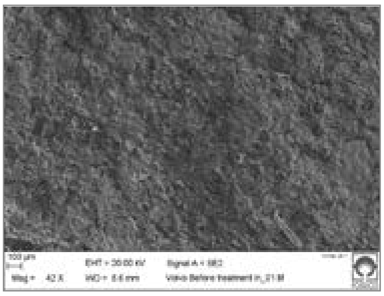
But before we go further, let us consider the coating in more detail:

After casting, the very complex cylinder head part has to undergo a number of treatments. This consists of sand shake-out, heat treatment and final shot blasting. The resulting casting surface for a conventional coating is shown in figures 4-6 at each of the process stages.

As coating is the first material the metal contacts when entering the mould cavity, the coating usually adheres to the cast surface in the as-cast state.

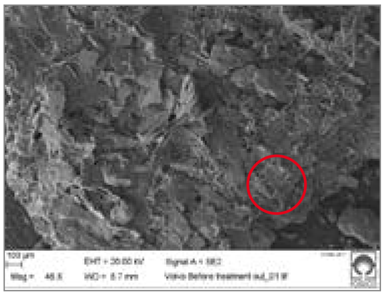
Casting is defect free, but sand still adheres to the inner surface:

SEM of coating layer on casting surface:



Fully sintered surface

SEM of coating layer sand side:

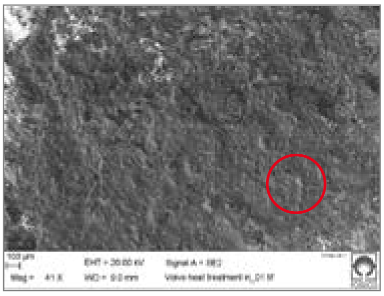


Still loose coating particles

Figure 4. Immediately after shake-out

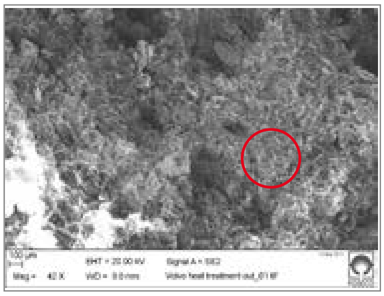
Coating layer adhering but starting to flake off:

SEM of coating layer on casting surface:



Fully fused surface

SEM of coating layer sand side:

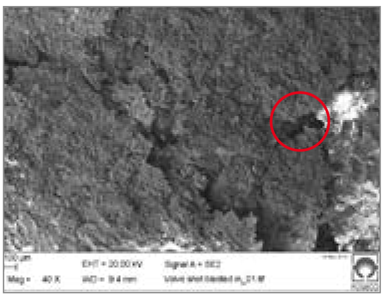


Sintered particles

Figure 5. After heat treament

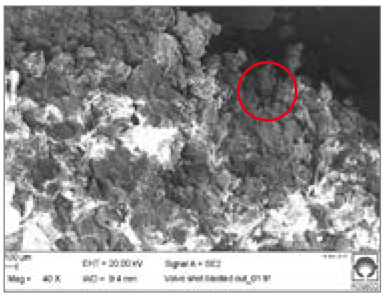
Coating still adhering in areas unreachable by shot blasting:

SEM of coating layer on casting surface:



Cracked but still adhering

SEM of coating layer sand side:



Sand and coating particles seem to create a network

Figure 6. After shot blasting

WHAT CAN BE ALTERED IN A COATING TO MAKE IT LESS ADHERING TO THE CASTING AFTER FINAL SHOT BLASTING?

One aspect is the coating flake formation. After pouring, the coating layer forms a ceramic shell that breaks down into flakes during shake out and further cleaning steps. These flakes could be used as a carrier for the debris adhering to them. By engineering the coating to form strong and well defined flakes that readily detach from the casting surface and do not themselves contribute (e.g. by disintegration) to further particle formation, it is possible to improve the cleaning of the casting even at inaccessible positions.

During trials the newly developed coating demonstrates how the correct ceramic shell formation helps to remove almost all remaining particulates, leaving a very clean casting surface (Figure 7 and 8). The result is an engine that performs better, longer and more efficiently.

Figure 7. Casting section only after shake out

Figure 8. Cast Surface right after shot blasting

FURTHER COATING PROPERTIES

Besides the coating flake effect, two more characteristics are important to produce a defect-free casting, which are Gas Permeability and Anti-Veining Properties.

Gas Permeability:
During the pouring process gas is developed by the binder combustion in a sand core. This means that the gas pressure behind a coating layer increases rapidly during the pouring process. In cases where the gas permeability is too low, coating can flake off and cause scabbing defects in areas that cannot be cleaned (in particular on cylinder head castings) and hence will lead to scrap.
Reading above about coating flake formation could lead to the idea that this new coating is very impermeable or in other words has a very low gas permeability. The opposite applies (Figures 9 and 10)

Foseco has developed a special test that enables the determination of a gas permeability in ambient and elevated temperatures.
Point A: Time at which the sample is put in the heated atmosphere
Point B: Time at which the sample scabs – immediate pressure drop
Distance A – B: Scabbing Resistance

In the above example, two values can be observed:

1. The lower the value on △p → the lower the pressure resistance → the higher the gas permeability in ambient conditions
2. The longer the curve expands the greater the scabbing resistance → the higher the gas permeability in elevated temperature conditions (here 1100°C)

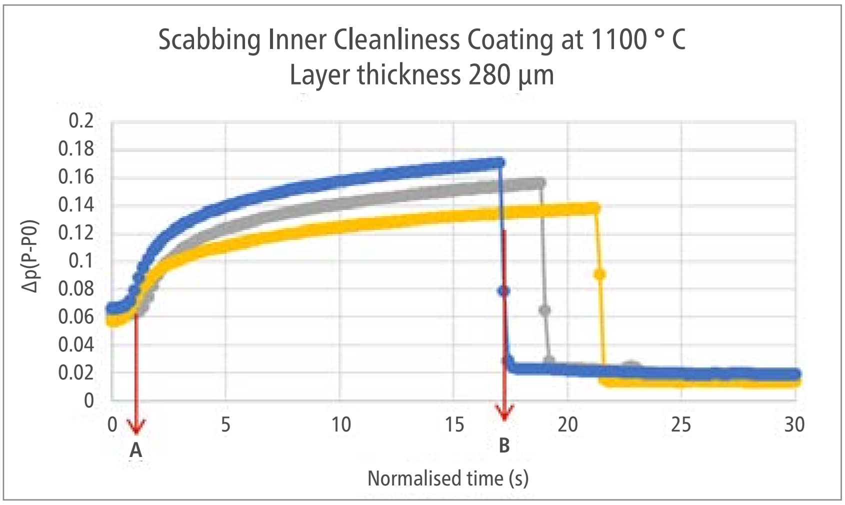


Figure 9. SEMCO* IC coating; showing extended resistance to scab formation

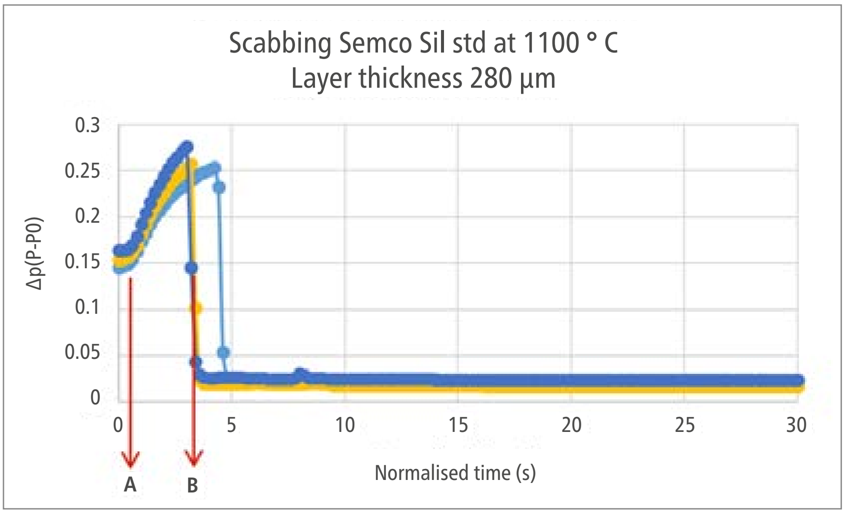
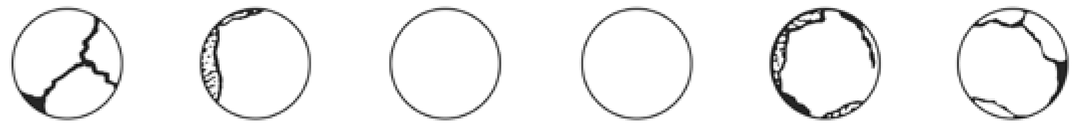


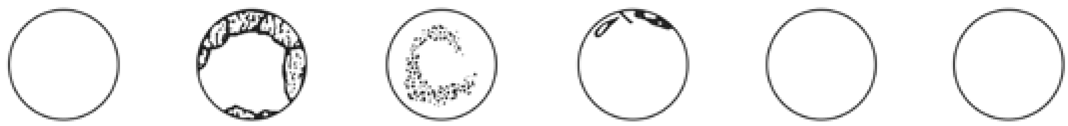
Figure 10. Conventional coating; showing poor scabbing resistance

ALTHOUGH THE NEW INNER CLEANLINESS COATING IS STRONGER IN TERMS OF CERAMIC FLAKE FORMATION, THE GAS PERMEABILITY IS STILL BETTER THAN A CONVENTIONAL COATING.



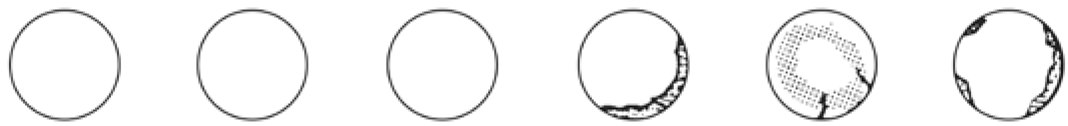
Core Composition	Silica Sand PU Cold Box Binder Zircon / Solvent Coating	Silica Sand PU Cold Box Binder Cold / Solvent Coating	Silica Sand PU Cold Box Binder Alu.silicate / Solvent Coating	Silica Sand PU Cold Box Binder Alu.silicate / Water Coating	Silica Sand PU Cold Box Binder Coke / Solvent Coating	Silica Sand PU Cold Box Binder Zircon / Solvent Coating
Result	Crack Formation	Veining	Good	Good	Veining	Crack Formation

Figure 11. Coating



Core Composition	Silica Sand Sodiumsilicate Binder Coke / solvent Coating	Silica Sand PU Cold Box Binder Cold / Solvent Coating	Silica Sand Furan (Phosphoric Acid) Coke / Solvent Coating	Silica Sand Furan (PTS Acid) Coke / Solvent Coating	Silica Sand Alkali Phenol Resin Coke / Solvent Coating	Silica Sand Bentonite Coke / Solvent Coating
Result	Good	Strong Veining	Good - some spots on surface	Some Veining	Good	Good

Figure 12. Binder



Core Composition	Special Sand PU Cold Box Binder Zircon / Solvent coating	Chromite Sand PU Cold Box Binder Zircon / Solvent Coating	Zircon Sand PU Cold Box Binder Zircon / Solvent Coating	Silica Sand PU Cold Box Binder Zircon / Solvent Coating	Silica Sand PU Cold Box Binder Uncoated	Silica Sand PU Cold Box Binder Coke / Solvent Coating
Result	Good	Good	Good	Veining	Veining and Metal Penetration	Veining

Figure 13. Sand

ANTI VEINING

Foundrymen consider the silica expansion at 573°C as the temperature at which the moulding material is most prone to veining defects. The best test to compare individual anti-veining properties of coatings is to conduct a veining block test. In this test, up to 6 different coatings can be compared side by side, keeping sand, binder and other parameters constant so that the pure coating performance can be determined. Figues 11-13 show an overview of options of anti-veining performance [5].

Comparing the conventional product (figure 14) with the new inner cleanliness coating (figure 15). It can be seen that the SEMCO* IC has higher resistance to vein formation.

Figure 14. Conventional Coating

Figure 15. Inner Cleanliness Coating

SUMMARY

A specially developed coating that can improve inner cleanliness in very complex engine components will help the automotive industry to achieve even more stringent emission demands than the current applied Euro 6 standard, but moreover also extend service intervals that will help to limit further resource depletion and improve our heritage for the next generations.

ACKNOWLEDGMENT

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