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THE PROPERTIES OF DIFFERENT BARRIER COATINGS

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Abstract: *Nowadays in power generation and racing sports cars and -cycles most of the components are protected by different coatings in order to achieve better resistive properties. Essential parameters are always resistance to failures and reasonable cost. Aluminum alloys are extensively used in the dynamically loaded structural components, however, their applications are hindered due to their low thermal stability. The pistons and cylinder heads made of Al-alloys in engines are subject to the elevated temperature and corrosive atmospheres during its operation. Heat, corrosion and oxidation resistant coatings are easily worn in these conditions. Therefore reaction speed becomes the most important parameter.*
Thermal barrier coatings do not react or react slowly. However, they are not stable at higher temperatures for longer periods. Deliberate defects like porosity or cracking might sinter together and decrease the cyclic behavior.
Keywords: ceramic coatings, barrier coatings, microstructure, thermal spray, bond strength

1. INTRODUCTION

The diesel or gasoline engine is most efficient production engine, yet devised by man with relatively unsophisticated cast iron metallurgy and aluminum alloys. For light duty engine applications the top three benefits are considered to be increased power density and reduced fuel consumption and inertia. The engine designers are continually searching for innovative and newer alternative materials to improve engine performance, higher power density and to increase durability and lower manufacturing costs. With the increase of power requirements the need for high strength cast iron has resulted the introduction of nodular and ductile iron for cylinder heads and blocks. In order to achieve strength properties between gray and ductile iron aluminum, with the advantage of not having casting and machining problems was introduced in the applications.
In recent years ceramics have received considerable attention from the engine designers and developers. Reduced engine heat rejection by the selected application of isolative ceramics is an approach that had been investigated to improve the engine fuel consumption, increase engine power density and reduce parasitic losses. While there is a steady increase in the use of ceramic components, there will be an evolution rather than revolution in engine design to take best advantage of these ceramics.
The automotive industry has been interested in using ceramics to insulate engine combustion chambers for two different reasons: firstly to reduce the size or to eliminate the cooling system, secondly to improve engine efficiency, while it might be assumed that a reduction in the heat energy,

which is lost to the coolant, would give an increase in mechanical output. However, the efficiency gain is in fact relatively small and most of the reduction in coolant heat appears as increased exhaust heat energy. The use of ceramics allows the engine to operate at elevated temperatures, reducing the amount of fresh air drowning by the intake stroke while increasing the temperature of the exhaust.

In thermodynamics, the engine concept has been developed by assuming zero heat loss i.e. an adiabatic process. The ceramic engine is not an adiabatic or without heat loss in the true thermodynamic sense, however, it is without conventional forced cooling and tries to minimize the heat loss. In the adiabatic process, the combustion chamber is isolated with high temperature materials to allow hot operation with minimized heat transfer. The hot or isolated high temperature components include piston, cylinder head, valves, cylinder liner, exhaust valves and exhaust ports. The components should have the following characteristics [1]:

- Thermal shock resistance
- Thermal stability
- Thermal conductivity
- Wear/Erosion/Corrosion resistance
- Fracture toughness
- Adherence to the substrate material
- Creep/Rupture properties (Flexural strength)
- Low thermal coefficient of expansion.

The aim of this paper is to use flame sprayed and LPAS coatings for improving surface properties of engine components. The main activities are to improve the thermal efficiency of engines by insulating the heat loaded components, increasing the life expectancy of elements, reducing fuel consumption and maintenance costs.

2. EXPERIMENTAL PROCEDURE

2.1. Coating materials and coating technology

Aluminum alloy specimens with dimensions of 25 x 5 mm in diameter are obtained from local engine piston manufacturing industry and cleaned with acetone and carbon tetra chloride and heated in the oven. The specimens are blasted with Al_2O_3 abrasive and coated with NiAl up to thickness of 200 µm and yttria stabilized zirconia up to 300 µm by flame spraying. The parameters used for blasting and flame spraying are reported in Table 1 and Table 2. For spraying in this investigation were used flame spray gun CDS 8000 and spraying distance 100…250 mm.

Table 1. Blasting parameters

Machine used	ILB 120
Grit used Al_2O_3	100…150 µm
Air pressure	0.6 MPa
Distance	40…50 mm

For the coatings also solvent based ceramic materials are used (Table 3.). HVLP (gravity feed) spray gun is used for spraying.

Table 2. Flame spraying parameters

Gun	CDS 8000
Spray distance	100…250 mm
Acethylene pressure	0.07 MPa
Oxygen pressure	0.4 MPa
Compressed air	0.3…0.4 MPa

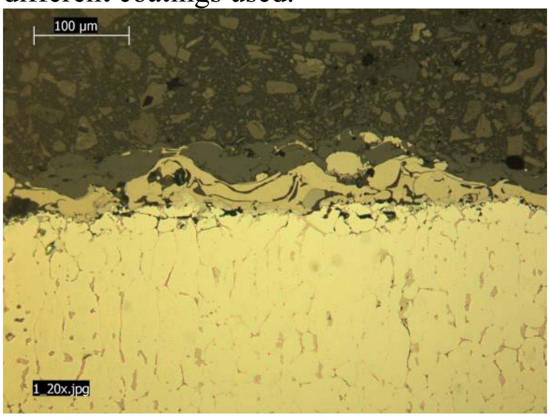
For comparing with the properties and technology were used the solvent based Ceramic coatings from NIC Industries Inc. The used coating materials were C-104, V-136 and W-207 working at following temperatures: C-104 500 K, V-136 890 K and W-207 1000 K.

Table 3. Compositions of solvent based ceramic materials [2]

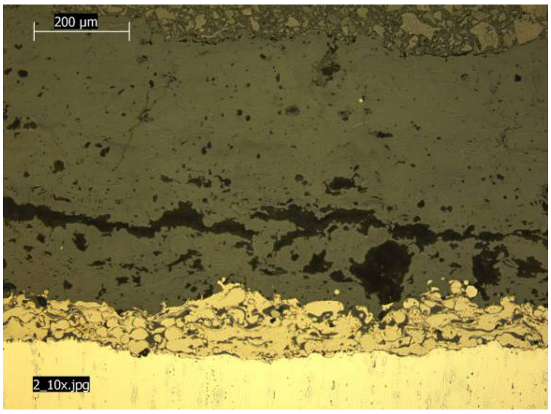
Coating material	Composition	Content [%]
C 104	Tert-butyl acetate Benzene Proprietary siloxane	35 ...45 25…30 20…40
V 136	Benzene , 1-chloro-4-trifluormethyl $Mg_3H_2(SiO_3)_4$ Proprietary Formulation	50…60 2,7…7 20…30
W 209	Al powder Phosphor acid Quartz MgO Chromiumtri(VI)oxide SiO_2 Al_2O_3 Chromium (III) oxide	30…50 10…35 8…10 < 5 <3 1…2 2…3 < 1

2.2 Structure of Coatings

The powder sprayed coatings had a thickness of thermal barrier coatings 0.2 – 0.3 mm and solvent based barrier coatings of 0.05 to 0.1 mm. In Fig. 1 and Fig. 2 are shown the micrographs of cross sections of different coatings used.

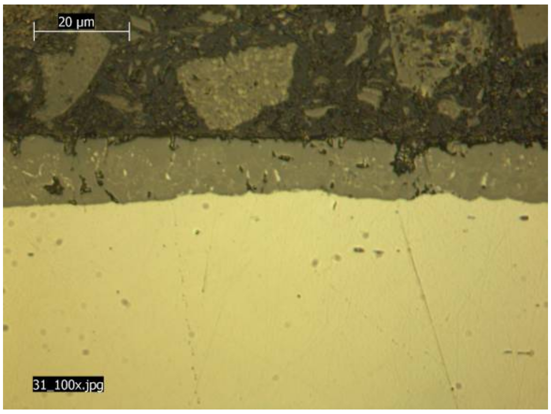


1.a)

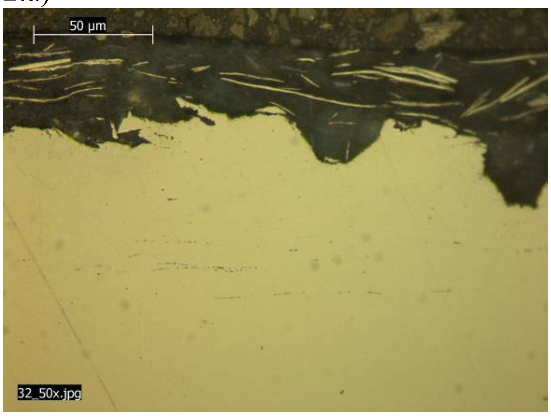


1.b)

Fig.1. Microstructures of powder coated specimens (1.a ZrO_2/30CaO 1.b ZrO_2/Y_2O_3)



2.a)



2.b)

Fig.2. Microstructure of solvent based ceramic coating V-104 (2.a- front elevation, 2.b- side elevation)

2.3. Bond Strength and Hardness of Coatings

The bond strength of coatings is the most important property which determines the field of use of coatings especially for thermal barrier coatings. For measuring the bond strength of coatings were used the special samples (Fig. 3). The diameter of centre pin of the specimens was 4 mm [3].

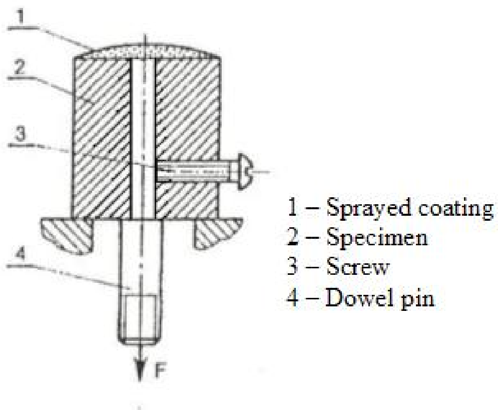


Fig.3. Specimen samples.

The bond strength of coatings used are given in Table 4 and coating properties in Table 5.

Table 4.The bond strength of coatings

Material	Bond strength [MPa]	Hardness [HV]
Castoline 28085 1)	32	700
ZrO2/Y2O3 2)	28	700
Under layer Castoline 51000	35	-

1) Castolin SA

2) Industriekeramik Hochrhein

Table 5. The used spray powders

Type of powders	Chemical composition	Particle size [µm]
Castoline 51000 1)	NiAl15Ti5Si1,5	+6 -120
Castoline 28085 1)	ZrO2/30CaO	+11 -53
ZrO2/Y2O3 2)	92ZrO2/8Y2O3	+45 -75

1) Castolin SA

2) Industriekeramik Hochrhein

3. RESULTS AND DISCUSSION

Adhesion strength value between the substrate and the under layer depends on the type of under layer deposition, spraying modes and the following thermal treatment which always exists in thermal barrier coatings.

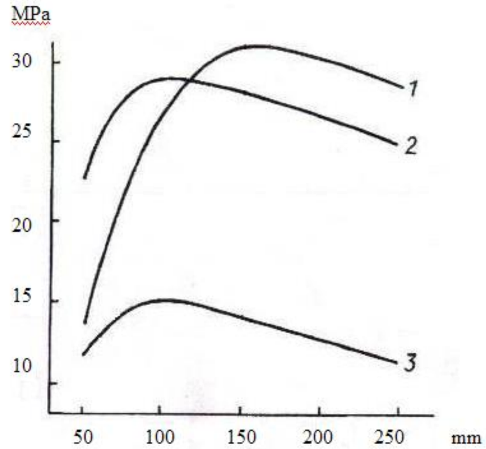


Fig. 4. Dependence of bond strength and spraying distance.

1) Castolin 51000

2) Castoline 28085

3) ZrO2/Y2O3

On the Fig. 4 we can see how the bond strength of the experimented coating depends of the spraying distance.

When working with thermal barrier coatings the most important criterions and properties to be considered are thermal expansion and thermal conductivity. The general thermal expansion for materials can be calculated according to the following formula:

$$\alpha = \frac{\gamma_G \rho C_V}{3E} \qquad (1)$$

where

γ_G – Grunesien constant; for most solids 1

ρ – Material density [kg/m3]

C_V – Volumetric specific heat [J/kgK]

E – Young's modulus [MPa]

Thermal conductivity

$$\lambda = a \rho C_p \qquad (2)$$

where

λ– Thermal conductivity [J/mK]

a– Thermal diffusivity [m2/s]

ρ – Material density [kg/m3]

C_p – Specific heat [J/KgK] [[4]]

In this experiment the thermal conductivity and thermal expansion are not calculated or measured but as from these parameters depends the coating material of under layer they are included to the research.

As an addition due to the materials being hard and brittle thermal shock resistance plays and important role for the barrier coatings. This property is essential when choosing the correct coating type and material [[5]].

The described coatings were used for different parts of engines in the experiment. On Figure 5 is shown ceramic coating Castoline 28085 and on Figure 6 is shown solvent based barrier coating V 136.

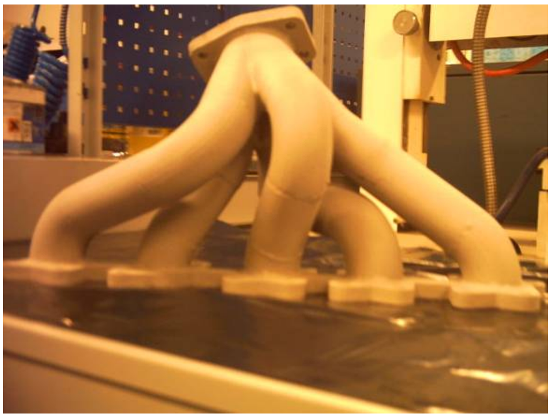


Fig.5. Barrier coating on exhaust collector.

Fig.6.Piston coated with V 136.

4. FURTHER REASEARCH

During the research process appeared that locally there are still a wide range of possibilities to continue with the research and experimenting. Also the experiments were carried out with few different coatings. As it appears the use of thermal barrier coatings gives an advantage for the engine work and material costs. Therefore we can summarize that further research with similar experiments in the field would be clearly justified, which also gives us the reason to continue.

For further research similar research with different coating materials about thermo shock resistance will be done in the future.

5. CONCLUSIONS

The following conclusions have been drawn for flame sprayed powder and solvent based ceramic coatings. The bond strength was investigated for flame sprayed coatings and it is an important property when using with thermal barrier coatings. The best results when using them are possible to achieve with plasma spraying. According to the results it can be concluded that using thermal barrier coatings with engine elements it is possible to rise highly the efficiency of the engine work and lower the costs.

6. REFERENCES

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