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Steel coating application for engine block bores by Plasma Transferred Wire Arc spraying process ☆

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A R T I C L E I N F O

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A B S T R A C T

Thermal spraying development for automotive industry grows since the end of the nineteen nineties. In the case of engine blocks, bores were before plated by a chemical process or liners were inserted in cylinders to ensure the tribological performances. In fact, aluminum has poor wear properties. Nowadays, a lot of research is conducted on the reduction of weight by liner replacement. The main solution is the coating application directly on the aluminum cylinder bore. In this way, weight is reduced and design can be improved to furthermore develop performance and efficiency. Different processes are employed such as plasma, HVOF or electrical arc. One of them is the Plasma Transferred Wire Arc spraying (PTWA) consisting of a plasma jet formed by a transferred arc between a cathode and a wire. Its tip is melted and blown by a gas blast toward the bore surface. This paper presents the PTWA process applied for cylinder bore coating. Typical coating is presented in terms of composition with two arc current intensities used. Tribological tests measurements were done and compared to the previous solution consisting of cast iron liner. Some technical and problematic points are presented around the spraying process in bores.

1. Introduction

Due to the global reduction of emissions (CO_2) [1,2], automotive sector is exposed to a nonstop evolution of legislations, tendencies, economics and comfort. In Europe, CAFE (Corporate Average Fuel Economy) and Euro standard [3] objectives are to decrease CO_2 and others polluting emissions such as NOx and CO. For example, in 2020, CO_2 emissions have to be lower than 95 g/km [4]. So, evolutions and researches have to be at the forefront of the technology [5]. Different solutions are studied in order to reach these objectives such as the car weight reduction (downsizing), the improvement of the combustion process, the use of hybrid or electrical vehicles, the friction reduction in tribological parts of engines, etc. [6]. And it is the specific case of the engine cylinder block.

100 years ago, cylinder blocks were only made of cast iron. In order to reduce the weight, cast iron was replaced 50 years ago by lighter aluminum. But because of its bad tribological behavior cast iron liners are inserted inside bores to keep the good performances. And for 20 years, liners have been replaced by thinner coatings [7]. So the weight is reduced furthermore, the inter-bore distance is decreased (downsizing) and tribological behavior can be improved. Surface treatment is one way which can solve problems for example regarding energy losses in car engine [8,9].

Actually, three processes are employed to perform this protective layer: powder based Atmospheric Plasma Spray (APS) developed by Sulzer Metco and used since a long time by VW, LDS (Lichtbogen Draht Spritzen) developed and used by Daimler AG and BMW, PTWA (Plasma Transferred Wire Arc) developed by Flame-Spray Industries and Ford Motor Company and used by Nissan and Ford. In each case, a spray jet in rotational motion goes up and down inside the cylinder. For engine blocks APS based device, the process applies a rotary plasma torch (Rotaplasma) supplied by a powder. LDS deals with a rotary twin wire arc spraying process supplied by two wires.

The PTWA process was developed by K. Kowalsky and D. Marantz from Flame Spray Industries [10–12]. It consists of a plasma system with a tungsten cathode and a copper nozzle (cf. Fig. 1). The torch head is on a rotating spindle. Plasma gases pass around the cathode. A high voltage discharge is applied between the cathode and the nozzle leading to plasma creation. Due to the small nozzle exit and the high pressure inside, the plasma is elongated and forced to be transferred outside from the torch to the wire extremity (new anode). The wire tip is melted. Because of the high pressure plasma gases and the atomizing gas blowing, atomized particles are generated and accelerated. A constant current maintains the plasma from the cathode to the wire which is itself in movement. Then the gun head, mounted to a rotating spindle, can rotate.

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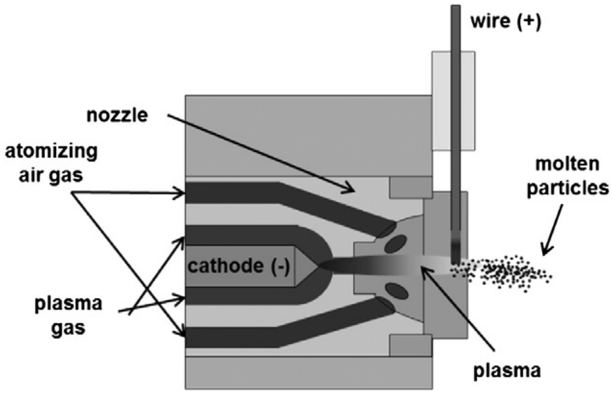

Fig. 1. Schematic of the PTWA process.

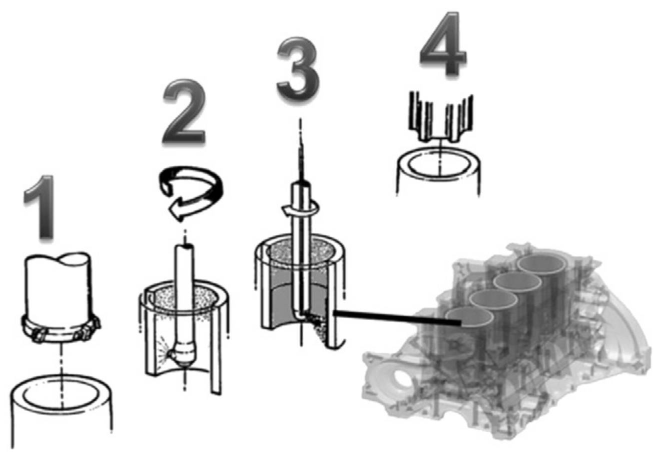

Fig. 2. Steps for coating application in bores: 1) bore machining, 2) surface activation of bore, 3) coating application and 4) coating honing.

Before bore coating, the preparation of the aluminum engine block requires several steps (cf. Fig. 2). After aluminum cast, cylinders are machined (1) in order to give them the correct diameter. Then, the surface of the bore is activated (2) to obtain the highest bonding strength for the coating: different processes (cf. Table 1) can be applied such as grit-blasting, high pressure water jet, mechanical roughening, etc. [13–15]. The coating is applied (3) and then honed (4) to become smooth.

The study presents the thermal spray coating manufacturing in bores by PTWA. Compositions are analyzed and tribological properties are studied to compare with conventional cast iron liner solution.

2. Experimental protocols

2.1. Around the project

PTWA process has been chosen for different reasons:

- PTWA process was available on the market (Turn Key Systems delivered by GTV) and a collaboration between PSA Peugeot Citroën and Ford exists. Flame Spray Industries and Ford have always developed the PTWA process with industrialization. So it's a mature process;
- LDS process was not available on the market at that time;
- Powder based process has a high industrial maturity but was considered too expensive for this future automotive application.

The surface activation is performed by grit-blasting because high series are considered and not only competition or high-end engines. A primarily study has shown that the cost can be reduced using grit blasting even if the mechanical roughening can be less cost effective too in other works [16] according to the number of pieces to be treated. Mechanical roughening is cheaper than grit-blasting but for complex profiles and a very high use some problems can appear. In the project, very high series are considered as 1500 engine day. So in this case, the cost would be higher and the mechanical tools will not be compatible to the number of engine blocks to be treated. An aluminum silicon four bores mounted in a straight line block has been used for this study.

2.2. Process, feedstock and related operating parameters

PTWA process (GTV, Luckenbach, Germany) is presented in Fig. 3. Two different torches are used: one operates with a maximal arc current intensity of 85 A and the other one with a max value of 150 A. The 150 A one is characterized by a smaller design (40 mm diameter compared to 57 mm for 85 A torch one). The operating parameters are given in Table 2. A high carbon steel wire with 0.8% C referenced 50.13.6 (GTV, Luckenbach, Germany) was used. The surface activation is performed with a RotaBlast (Oerlikon Metco, Wohlen, Switzerland) 360° rotary grit blasting device presented in Fig. 4. Corundum particles are deflected and blown toward the surface of bores by a rotary air deviation nozzle. The RotaBlast is mounted on a robot ABB 4400 to move up and down in bores. Corundum mass flow rate and velocity and the deviation air pressure are adjusted to get the optimal roughness of the aluminum substrate surface. Then bores are blown by compressed air.

2.3. Characterization techniques

Coatings were analyzed with an optical microscope (Olympus Vanox AHMT 3, Hamburg, Germany) equipped with a camera (Leica DFC 320, Wetzlar, Germany). The software "AnalySIS docu" (Olympus, Hamburg, Germany) was used to perform picture acquisition and analyses. Measurements and amount of porosity and oxides were determined with an average of 12 pictures.

Table 1
Examples of characteristics of main activation processes for bore coating.

	Advantages	Drawbacks
Grit blasting	• Cost • Cycle time per bore • High compression strength • Widely used	• Inclusion of corundum particles • Cleaning after process • Decrease of the corundum average size all along the process (use of an automatic grit reconditioning system)
High pressure water jet	• Low qualification level for staff • Large activated area with simultaneous cleaning • Low qualification level for staff	• Very aggressive for soft materials • Non-homogenous surface • Long cycle time
Mechanical roughening	• Other applications cleaning, cutting, etc. • Very homogenous activation • Profile control and modification • Very high bonding strength	• Drying step necessary to avoid corrosion • Long cycle time • Tool cost • Tool wear control