

Interpolated Selective Area Mechanical Roughening for Thermally Sprayed Engine Bores

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ABSTRACT

Thermally sprayed engine bores require surface preparation prior to coating to ensure adequate adhesion. Mechanical roughening methods produce repeatable surfaces with high adhesion strength and are attractive for high volume production. The currently available mechanical roughening methods are finish boring based processes which require diameter-specific tooling and significant clearance at the bottom of the bore for tool overtravel and retraction. This paper describes a new mechanical roughening method based on circular interpolation. This method uses two tools: a peripheral milling tool, which cuts a series of concentric grooves in the bore wall through interpolation, and a second rotary tool which deforms the grooves to produce an undercut. This method produces equivalent or higher bond strength than current surface preparation methods, and does not require diameter-specific tooling or bottom clearance for tool retraction. In contrast to boring-based methods, it also permits roughening and coating only a portion of the bore (e. g. the ring travel portion), reducing steel wire and energy consumption and enabling the elimination of a bimetallic cut on the joint face of the block. Following a review of existing mechanical roughening methods, the interpolation method is described, including finite element analysis, adhesion testing to optimize profile dimensions, and preproduction testing. Finally, low volume production experience for a V8 engine and the application of the method to brake rotor mechanical roughening are discussed.

CITATION: Stephenson, D., "Interpolated Selective Area Mechanical Roughening for Thermally Sprayed Engine Bores," *SAE Int. J. Mater. Manf.* 10(3):2017, doi:10.4271/2017-01-0452.

1. INTRODUCTION

Thermally sprayed coatings have been used in place of cast iron bore liners in a number of low and high volume aluminum engine block applications [1-7]. Reported advantages of the coatings include weight reduction, improved heat transfer, improved packaging, and friction reduction.

The application of these coatings requires proper preparation of the bore surface to ensure adhesion [8]. In recent applications the bore surfaces have been prepared by grit blasting, high pressure waterjet activation, or mechanical roughening. Grit blasting and waterjet activation have been proven reliable but produce irregular surfaces which are difficult to gage for production control. Mechanical roughening yields high adhesion strength and produces a repeatable surface which is more readily characterized and gaged, making it well suited for production control in higher volume applications.

The currently available mechanical roughening processes are single-point boring processes which require diameter-specific tooling; this is of concern in flexible production systems with limited tool changer capacity, since separate tools are needed for each required bore diameter. These methods also require significant clearance at the bottom of the bore for tool overtravel and retraction. This paper describes a new roughening method based on circular interpolation rather than boring. This method provides high adhesion strength and does not require diameter-specific tooling or bottom clearance for

tool retraction. In contrast to boring-based methods, it also permits roughening and coating only a portion of the bore (e. g. the ring travel portion), reducing material and energy consumption and enabling the elimination of a bimetallic cut on the joint face of the block. This method is used in low-volume production for the Ford 5.2l V8.

Current boring-based mechanical roughening methods are reviewed in [Section 2](#), together with adhesion results from initial tests. The new interpolated process and associated tooling are described in [Section 3](#). Finite element studies and adhesion testing of profile dimensions are discussed in [Section 4](#). Preproduction testing and low volume production experience are summarized in [Section 5](#). Finally, tooling details and test results for the application of the method to brake rotors are discussed in [Section 6](#).

2. BORING-BASED PROCESSES

The first reported mechanical roughening process was the Nissan Mechanical Roughening Process (NMRP), developed by Nissan for a V6 application [4,9]. The NMRP is a single-point boring process which uses a triangular tool similar to a threading insert. The insert cuts a spiral, V-shaped groove. The tool's lead and rake angles are selected to direct the chip produced in cutting against the top of the adjacent groove, which produces deformation and intermittent undercuts.

The Honsel Mechanical Roughening Process (HRMP) [5,10] was developed by Honsel and Gühring and used on the Ford 5.4l and 5.8l Shelby Mustang Engines. The HRMP is also a single-point boring process using a zero-lead, square PCD insert in which fine-scale dovetail cutting edges have been cut by wire EDM. The tool and the dovetail profile it produces are shown in Fig. 1. The cutting section of the insert is roughly 10 mm long, and the wavelength of the dovetail profile is 400 μm .

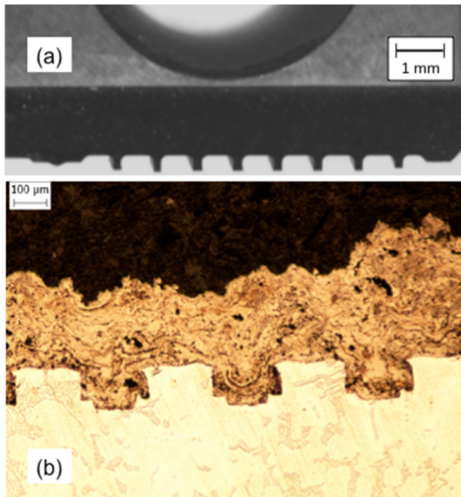


Figure 1. (a) Profiled insert used in the Honsel Mechanical Roughening Process (HRMP). (b) Surface profile produced by the process.

The Braunschweig process [11] was developed at TU Braunschweig as part of the German Bundesministerium für Bildung und Forschung (BMBF) “NanoMobil” project (Grant 03X003). Like the HRMP, it is a single-point boring process using a profiled PCD insert. As shown in Fig. 2, the insert is simpler, with a cutting section length of about 5 mm, and cuts a crown-shaped profile with a wavelength of 300 μm . The recently reported roughening process used in a Porsche Boxer engine application [12] is also a single-point boring process using a profiled PCD insert.

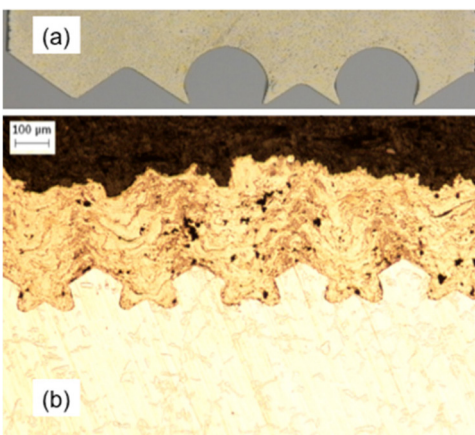


Figure 2. (a) Profiled insert used in the Braunschweig Process. (b) Surface profile produced by the process.

Roughening and coating adhesion tests were performed with test tools for both the HRMP and Braunschweig processes. In these tests 200 sand cast 319 Al liners, 80 mm ID and 130 mm long, were roughened with each process. Liners were machined at 2200 rpm (550 SMM), using 40 ml/hr minimum quantity lubrication (MQL) synthetic ester oil. The feed rate, determined by the profile wavelengths, was 0.4 and 0.3 mm/rev for the Honsel and Braunschweig processes, respectively. Roughened liners were coated using the Plasma Transferred Wire Arc (PTWA) process with 1010 steel wire; the coating thickness was 800 μm . Adhesion tests were performed using a PAT tester from DFD Instruments, Kristiansand, Norway [13] (Fig. 3), a hydraulic device that measures the force required to break the coating-substrate bond in tension. The force is transmitted through a test plug glued to the surface, so the test underestimates strength if the glue rather than the coating fails.

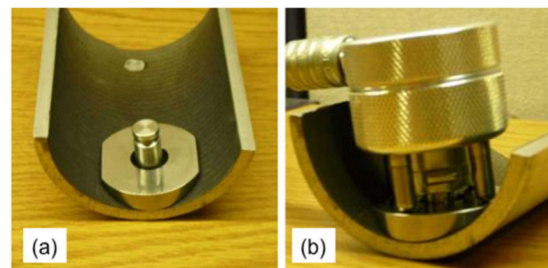


Figure 3. (a) Adhesion test plug glued to coated cylindrical surface, with surrounding support washer for test head. (b) Test head for measuring the tensile force required for coating failure.

Adhesion test results are summarized in Fig. 6. Both processes provide consistent adhesion strength well above the process minimum specification, which is typically 20-25 MPa. Average adhesion values were 60 ± 3 MPa for the Braunschweig process and $> 48 \pm 4$ for the Honsel process. Adhesion strengths for the Honsel process are underestimated in these tests since the glue rather than coating failed in all but one case. Gand reports a value of 56 MPa for this process based on tests on 356 aluminum liners [5].

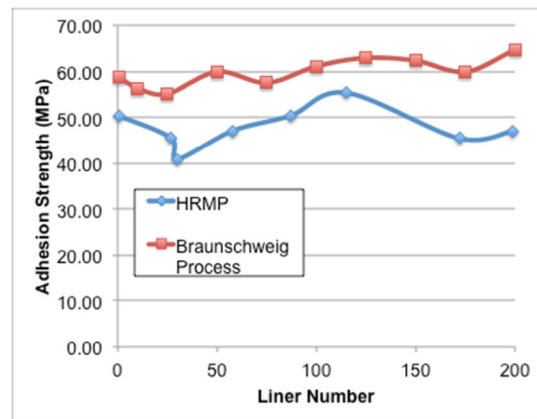


Figure 4. Adhesion test results for 200 liner tests of the HRMP and Braunschweig processes. Adhesion values for HRMP are underestimated since many tests produced glue failures. Both processes provide adhesion strength much higher than required for the application.