

Lubrication on Demand: A Novel Polymeric Bearing Coating with Oil-Filled Microcapsules

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ABSTRACT

Modern High-Speed Diesel (HSD) engines place increasing demands on engine components. Specifically, for connecting rod bearings there is a requirement to endure increased peak cylinder pressures and the resulting loads transmitted through the connecting rods to the crankshaft. In addition to these high loads, the operating environment for bearings is becoming more aggressive. Reductions in oil film thickness combined with the move towards lower viscosity oils means that the seizure and wear resistance of the bearings play a crucial role in modern engine development. In order to attend to these demands, MAHLE has developed a novel high-performance polymer coating containing lubricant-filled microcapsules.

The Microcapsules are designed to rupture during nascent scuff and high wear events and consequently release the contained lubricant 'on demand'. This introduces additional lubrication when required to prevent seizure.

A clear tendency for the novel polymer coating to provide improved recovery after scuffing events was measured, allowing for continuing safe operation of the bearings and thus reducing the seizure risk. Testing shows that microcapsules improved the recovery rate after seizure events to 66% whereas conventional polymer overlays show a recovery rate of 25%. As an additional benefit, the microcapsule-filled polymer coatings provide a wear improvement of more than 20% compared to current polymer bearing coatings. Simultaneously, they maintain the exceptional fatigue performance expected of polymer overlay coatings.

The present paper reviews the development of the novel polymeric overlay with lubricant-filled microcapsules and details rig test as well as engine test results.

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INTRODUCTION

The drive to increase engine efficiency and reduce emissions creates new challenges for bearing manufacturers. Down-sizing of engines increases the loads experienced whilst stop/start applications simultaneously contribute to increased wear. These factors combined with reduced oil viscosity and oil film thickness contribute to a more aggressive bearing environment than ever before. Therefore, improving the seizure and wear performance of automotive plain bearings is a continuously evolving challenge [1].

Polymeric coatings for plain bearings are the state-of-the-art solution for the most demanding applications such as HSD engines [2]. Such polymeric coatings tend to consist of a highly temperature stable polymeric matrix such as Polyamide-imide (PAI) combined with solid lubricants and other tribological additives and pigments. Figure

1 shows a graphical representation of the layered structure of an automotive plain bearing detailing the steel backing, lead-free bronze substrate and polymer coating.

However, due to the continuing developments outlined above, it is necessary to further enhance the current polymeric coatings. It is this drive for additional performance that has led MAHLE to develop micro-encapsulated additions for polymeric bearing coatings. The present work considers the addition of oil-filled microcapsules to the current polymeric coating product applied to bronze substrates for applications in HSD engines. The rationale was to provide improved seizure performance and wear performance via 'lubrication-on-demand'. A schematic of the lubrication-on-demand concept is shown in Figure 2. The figure shows the result of wear event caused by a tribological partner. The microcapsules are opened via wear or scuff events which allows them to release their contents of oil to aid lubrication.

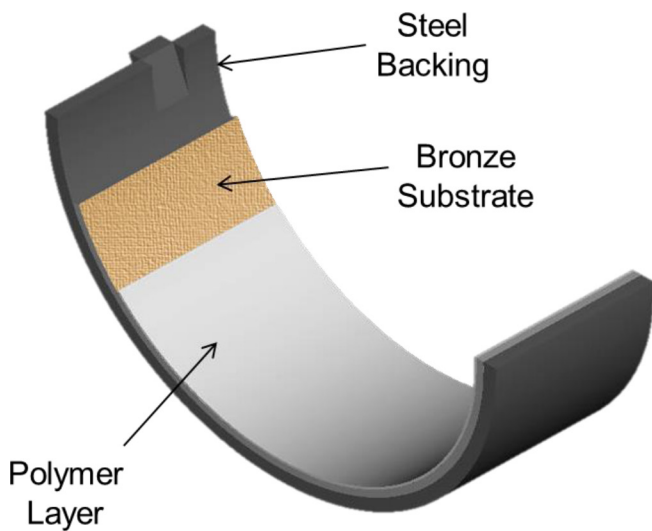


Figure 1. Graphical representation of a polymer coated automotive plain bearing with a bronze substrate and steel backing

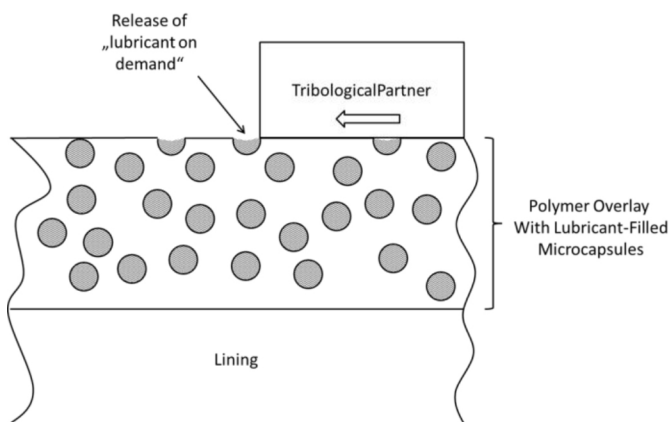


Figure 2. Schematic of 'Lubrication on Demand' concept.

A representation of a bearing with the microcapsule coating is shown in Figure 3. It can be seen that the microcapsules on the surface have been opened and released additional lubrication. Furthermore, the open microcapsules at the surface act as small oil reservoirs which will retain oil when the engine is switched off. This could provide additional wear and friction benefits as oil is available immediately upon start up without the short delay normally required for the oil system to pressurize.

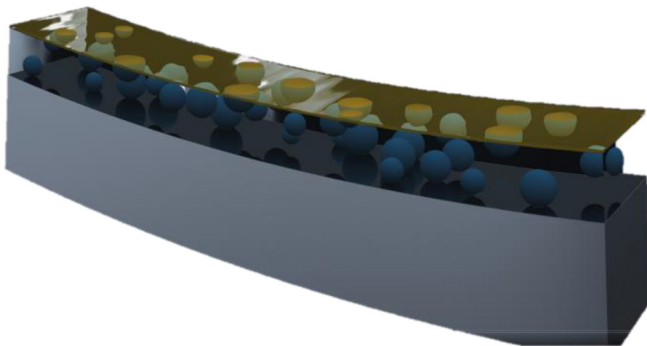


Figure 3. Representation of a bearing coated with the microcapsule material

Microencapsulation is a process whereby droplets of a material can be encased by a second shell material to produce a microcapsule. The encapsulated media is referred to as the 'core' and the casing is termed the 'shell'. Microencapsulation is normally used when the substance in question is either difficult to incorporate into a parent material or when its release is only required under specific situations. For example, microcapsule technology is widely used to carry fragrances in washing powders and deodorants and can be used to help food retain its flavor [3,4]. The cost of fragrances and their volatility means that it is more economical to encapsulate them so that they are only released when they are required. Release is controlled via the selection of suitable microcapsule shell materials. Materials are specifically chosen to break down under load, at a certain temperature etc.

There are a wide range of methods for the production of microcapsules. These methods can be broadly split into those that are Physical and those that are Chemical [5, 6, 7]. Physical processes include methods such as pan spraying, air suspension or spray drying. These physical methods rely on a solid core material onto which the shell material can be deposited by spraying, rolling etc of the core particles. Chemical methods tend to be preferred for non-solid core materials and include coacervation and sol-gel approaches. The present work focused on the encapsulation of oils so a coacervation method was selected. This approach requires three immiscible phases; a liquid transportation phase (also known as the manufacturing media), a liquid core phase and a liquid shell phase. The method consists of three stages. Firstly, the core material is added to the transportation phase and an emulsion of the core material is created by rapid agitation. The final size of the microcapsules can be controlled at this stage by altering the stirring speed and, hence, the oil droplet size [8, 9]. As such, the viscosity of the core material is a limiting factor. Secondly, microcapsules are created by the addition of the shell phase. The shell material coats the droplets of the core material to form a thin wall [10]. Finally, the shell must be rigidized to prevent the egress of the core material. This can be achieved by reactive cross-linking or a thermal treatment depending on the chosen shell material; a schematic of this process is shown in Figure 4.

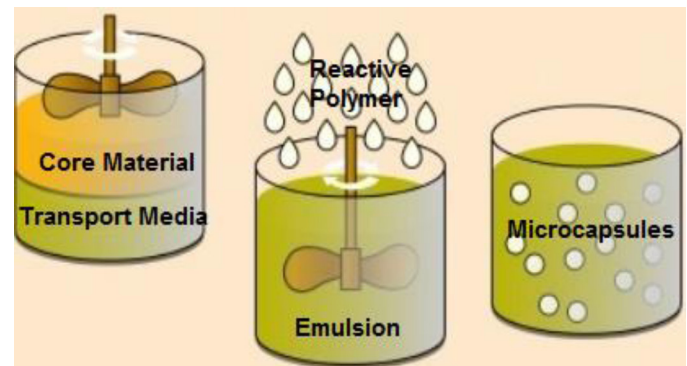


Figure 4. Schematic of the microcapsule production process. (Adapted from www.pharmatutor.org [11].)

Much of the present microcapsule literature is concerned with encapsulation for non-aggressive and low temperature operating conditions such as fragrances. However, the novel coating developed

during the present work required microcapsules with a shell material capable of withstanding the operating temperature inside an engine and the associated aggressive environment.

EXPERIMENTAL

Microcapsule Production

The polymer selected for the microcapsule wall in the present work was melamine due to its high strength and temperature performance. Melamine is also resistant to solvents which was essential to allow the microcapsules to be incorporated into a sprayable solvent-based polymeric coating system for automotive plain bearings. Optimization of stirring speed and core material viscosity was performed in order to produce microcapsules of a suitable diameter and size distribution. A number of different oils were investigated to ensure compatibility with the shell material. The requirement to balance the viscosity and pH of the coacervation encapsulation process led to the selection of heavy mineral oil as the core material.

Rig Testing

In-house rig testing was conducted in order to rank the Microcapsule containing polymeric materials against current polymer products. All rig testing was performed using a standard size of steel-backed plain bearing half shell with dimensions comparable to current production parts for passenger cars. Lead-free bronze substrates were used for all testing as these are standard for connecting rod use in HSD engines.

Wear Testing

Wear testing was conducted on an internally developed accelerated wear test. The test generates high specific loads and operates under boundary lubrication. The test rig is referred to as "Viper" and a schematic of the test is depicted in Figure 5. The bearing half shell to be tested is mounted in a solid housing. The wear partner is an eccentric shaft, which is rotated at a speed of 500rpm. A constant operating load is provided by a dead weight. Heated oil is provided throughout the test to produce a boundary lubricated regime.

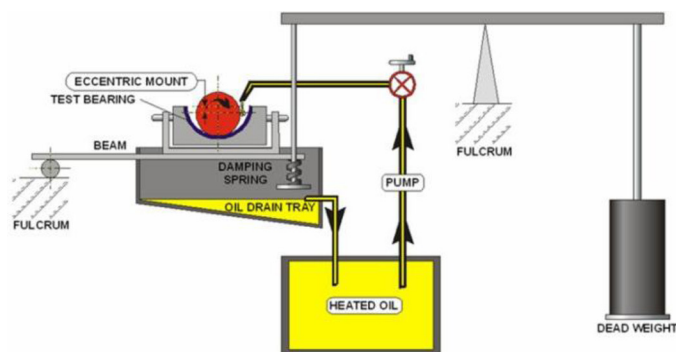


Figure 5. Boundary lubricated 'Viper' accelerated wear test rig

Typical test conditions of the Viper accelerated wear rig are summarized in Table 1. Bearing overlays are tested for 60 minutes and the mass loss of the test bearing is determined by weighing the test pieces before and after the test. Six bearings are tested and the results are analyzed statistically. The mass loss is converted to a

volume loss using the known density of the material. This allows different overlay materials to be ranked. Six parts are tested per material to generate confidence bands.

Table 1. Viper accelerated wear test rig operating parameters

Test Parameter	Value
Shaft	Hardened Steel
Speed	500 RPM
Test Load	5.6kg dead weight on fulcrum
Oil Temperature	120°C
Lubricant Oil	PAO Synthetic oil, 46mm ² /s @ 40°C

Fatigue Testing

Fatigue performance of a bearing material is assessed via a standard 'Sapphire' fatigue rig. The test can apply a fatigue load via an eccentric shaft and a hydraulic ram to mimic the loading from a piston. The test runs for 20 hours and subjects the bearing shells to 3.6 million cycles. A schematic of the test is shown in Figure 6.

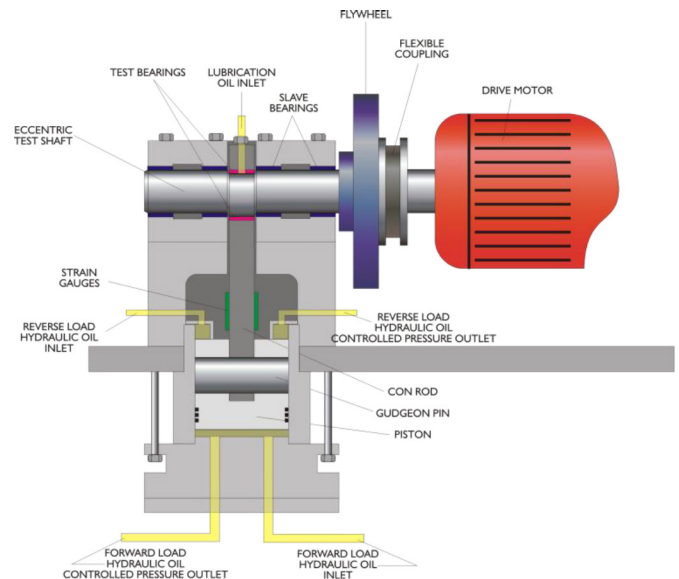


Figure 6. Schematic of the 'Sapphire' fatigue test rig

The test parameters of the Sapphire fatigue test rig are shown in Table 2. A fatigue test is conducted on ten test specimens and requires an 80% pass rate at a specified load to be considered successful.

Table 2. Sapphire fatigue test rig operating parameters

Test Parameter	Value
Shaft	Hardened Steel
Shaft Finish (Ra)	0.15 – 0.25 μ m
Speed	3000 RPM
Oil Temperature	110°C
Lubricant Oil	PAO Synthetic oil, 46mm ² /s @ 40°C