

CRANKSHAFT BEARINGS FOR ENGINES WITH START-STOP SYSTEMS

The challenges placed on engine bearings are growing along with the improving efficiency of modern combustion engines. Depending on the driving situation, fuel-efficient start-stop systems for instance increase the number of cycles that take the crankshaft and the bearing half shells through a phase of mixed film lubrication. A new overlay from Federal-Mogul based on reinforced polyamide-imide prevents wear which metallic sliding surfaces tend to show during such punishing use.



Crankshaft bearing shells with Irox overlay

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INCREASED WEAR CAUSED BY START-STOP SYSTEMS

Plain bearings used in the engine have to be designed for ever increasing specific load collectives. This includes rising firing pressures, higher temperatures, smaller bearing dimensions and a rising level of crankshaft deflection which is caused by lightweight designs. Oil viscosity that is getting lower as a tendency and the higher level of oil dilution caused by fuels such as E85 are only a few more of the many issues on an increasingly long list of tough operating conditions. Nevertheless, plain bearings shall have the lowest possible coefficient of friction to limit the engine's internal losses.

Start-stop systems, which can be found in more and more vehicles today, pose a particular challenge. They increase fuel efficiency by 5 % and more through switching off the engine during standstill as often as possible. To avoid any impact on drivability, the engine is cranked very quickly as soon as the driver engages the clutch.

For the crankshaft bearing half shells and the big end bearings this can translate into frequent high-speed rotary movement before a hydrodynamic film is established. During this phase of boundary lubrication metal-to-metal contact can occur between

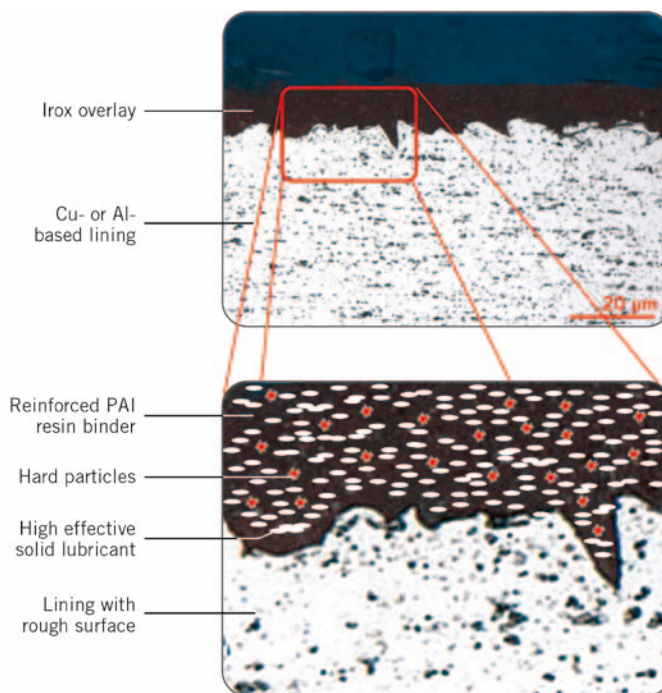
the crankshaft surface and the bearing's sliding surface. This was not an issue while the number of engine re-starts totaled at what was generally understood to be a normal magnitude. However, in a vehicle with start-stop system this effect can necessitate new technological solutions to avoid premature bearing wear, depending on the driving cycle. Consequently future engines for start-stop applications need to be designed for 250,000 to 300,000 starts. Traditional bearing shells with aluminum or copper lining show severe wear after only 100,000 cycles.

A newly developed coating called "Irox", for which patent is pending, is a counter measure based on polyamide-imide with additives. This overlay prevents bearing wear even during frequent mixed lubrication phases and is thus optimally designed for start-stop operation – this applies even to applications with cast iron crankshafts. On top of that the new overlay makes half bearings with aluminum (Al) based lining so much more robust that they can be used in applications previously considered to be the realm of copper (Cu) based linings.

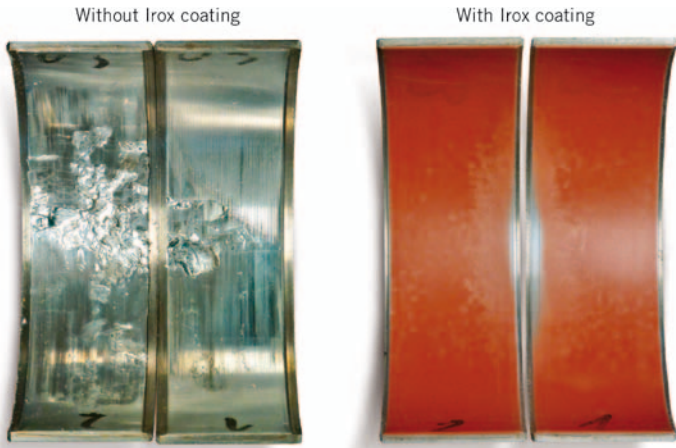
MATERIAL STRUCTURE

The new sliding bearing matrix consists of three elements: The steel back ensures dimensional and mechanical strength of the half bearing. On top of this a lining substrate is applied that provides the appropriate tribological material properties for the individual application. Throughout modern mass production vehicles these linings are made from lead-free substrates, most often either based on aluminium (Al) or copper (Cu) alloys. Typically Al based crankshaft bearings are used for low to medium specific loads (≤ 70 MPa), while Cu based (CuNi2Si) bearings are used for medium to high specific loads. To a large extent bearing durability depends on the top layer. With Irox bearings this overlay consists of polyamide-imide (PAI) with additives, ①.

The hard-particle reinforced PAI overlay is permanently bonded to the lining and forms a durable layer. Within the resin matrix several additives are evenly dispersed, some of which have a very fine grain. The bearing's typical reddish brown color is owed to micro reinforcement by finely distributed oxide particles. Another



① Schematic representation of the matrix system's design



② Bearing shells lined with the A-650 Al alloy substrate after endurance testing on an Underwood rig with 80 MPa for 250 h

type of not quite so finely grained hard particles also serves to increase the sliding layer's wear-resistance. Additional solid lubricant particles embedded in the matrix ensure good sliding properties during local metal-to-metal contact.

PAI is an amorphous highly temperature resistant polymer that well resists chemical attacks and wear. The material also lends itself ideally to be processed for the current application. Basically the overlay made from PAI and oxides can be applied and bonded equally well to the typical bearing linings made from aluminum or copper or bronze materials.

BEHAVIOUR DURING OPERATION

The Irox overlay's wear resistance is owed to a combination of several specific material properties. Its wettability causes the hydrodynamic film, essential for the correct function of a plain engine bearing, to build up faster. Also the micro reinforced PAI overlay is an elastic layer. Due to its lower modulus of elasticity it is better suited to compensate asperities in the topography of its running counterpart and thus shows excellent wear resistance.

Prior to applying the hard particle reinforced PAI the substrate is roughened-up to a specific level, ①. During bearing operation this generates two benefits: Firstly, the reinforced PAI overlay can cope very well with axial thrust load from whichever direction as the mechanical interlocking with the substrate on a micro level ideally supports loads. Secondly, the micro-mechanical interlocking with the substrate caused more beneficial wear characteristics. If the overlay is worn away locally, the many substrate asperities prevent the abra-

sion to advance because the metal-to-metal contact is limited to the microscopic peaks. Even in the case of edge loading the overlay will not show fissures but limited local wear only. This appears to be quite relevant as bearing damage and seizure of Al based substrates typically begin with crack initiation, subsequent crack advance and finally escalation.

Another material property is relevant in this context: The hard particle reinforced PAI overlay's elasticity has a positive effect on the plain bearing's damping properties. At the same time the PAI matrix maintains a certain capacity for embedding micro particles.

As PAI is a poor heat conductor the overlay limits the heat input to the substrate below. This turns out to be particularly beneficial with Al based substrates. As far as the roughness requirements to the sliding counterpart are concerned, the Irox matrix is no different from other crankshaft bearings. Instead, the new overlay matrix shows a superior behavior when run against a cast iron crankshaft.

SUITABILITY FOR CAST IRON CRANKSHAFTS

Using crankshafts made from grey cast with fine spherical nodules of graphite (Nodular Cast Iron, NCI) poses special requirements to plain bearings. A characteristic of NCI's morphological structure are hard ferrite envelopes around the graphite nodules. Despite even the most careful surface machining via polishing these circular structures covered by caps will not fully disappear. Those caps may break off during running condition and damage the bearing surface. If the bearing

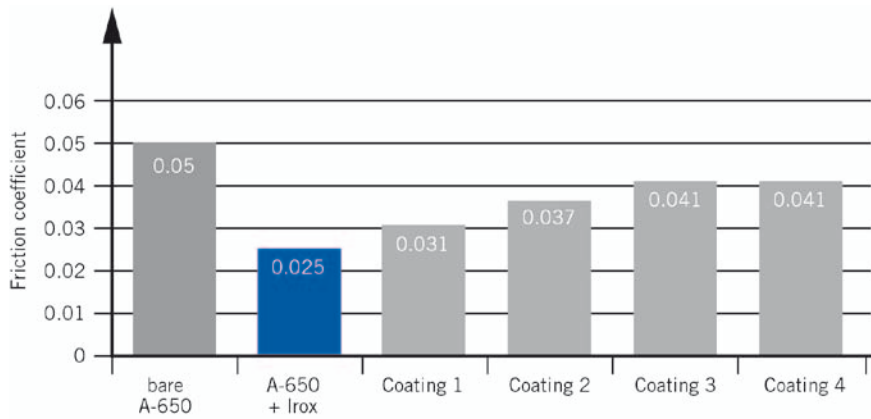
has no suitable mechanism to compensate this effect, cast iron crankshafts can quickly cause bearing seizure. With the Irox overlay, a combination of the embedded hard particles' polishing effect and the polymer's ductility prevent this type of problem from occurring.

TEST RESULTS

To verify the new layer matrix's suitability for the severe requirements of start-stop systems, the plain bearings had to pass multiple harsh tests. ② shows the surface conditions of two crankshaft bearing half shells lined with the same A-650 substrate, an Al alloy (AlSn6Si4CuMnCr) with improved micro structure. One of the bearings has an additional Irox overlay while the Al substrate itself serves as sliding surface in the case of the reference bearing.

Both material systems were tested at 80 MPa load on an Underwood rig under identical boundary conditions. Even though A-650 is a new high strength Al alloy with particularly fine silicon particles, its sliding surface shows considerable damage, while the Irox overlay shows only very limited local wear along the edges. This test result highlights very clearly just how much the overlay properties dictate whether a bearing substrate is suitable for a specific application or not.

Bearing half shells with Al substrate and the Irox overlay had a substantially improved fatigue resistance. Thus the new overlay matrix can toughen up Al based crankshaft bearing half shells for specific loads that are up to 25 % higher – a magnitude that was hitherto reserved for Cu based systems. When applied to Cu based substrates, the Irox overlay successfully



③ Coefficients of mixed friction of the tested sliding surfaces in comparison

passed engine test runs with up to 105 MPa specific loading.

During further test runs on a High Frequency Reciprocating Rig (HFRR) the Irox overlay reduced the coefficient of friction by half when compared to a bare A-650 Al substrate sliding surface. Even in comparison to other polymer overlays, used to coat piston skirts for instance, the Irox overlay's coefficient of friction was lower by 20 % to 40 %, ③.

In ④, results of various bearing types in one of many tests are shown, here in a so called "Sapphire test bench". In many start-stop cycling tests, the wear of the Irox bearings amount to a significant lower level than that of sputter bearings, known for their perfect wear resistance. The result has been consistent and reproducible through all of the tests.

The Irox bearings were tested in engine tests with standard gasoline as well as

with E-85. Despite the ethanol share of the E85 and the subsequent oil dilution caused by the alcohol, the Irox matrix's wear characteristics did not change, while a two-layer Al bearing lined with the common entry-level A-590 substrate (AlSn6Si-4CuMnCr with coarser silicon particles) failed during the E85 test run.

It can be deduced from these findings that the new layer matrix offers a potential for saving fuel by using engine oil with lower viscosity. It could also be proven during tests that the Irox overlay is less sensitive to small bearing clearances.

SUMMARY AND OUTLOOK

The new Irox overlay matrix is a solution tailored for combustion engines with a high share of mixed lubrication. The durable overlay made from micro reinforced PAI prevents premature abrasive wear, which metallic sliding surfaces can show under such operating conditions. Due to its high temperature resistance, its good damping properties and its robustness against oil dilution, e.g. caused when E85 fuel is injected, the new overlay matrix is suitable for use in modern passenger car and truck engines with high thermo mechanical efficiency and correspondingly tough requirements to engine plain bearings. The micro reinforced PAI overlay can also contribute to the use of engine oils with low viscosity (High-Temperature High-Shear Rate, HTHS 2.6 to 2.1). Large scale production for the first series application is scheduled to commence in April 2011. Further development work will be dedicated to exploring the Irox overlay's potential for use in highly loaded ancillary components, on thrust washers and for use in automatic transmissions.

