CIMAC CONGRESS 23
BUSAN, JUNE 12 – 16, 2023

2023 | 025

Bearing testing and validation to optimize bearing design for different engine applications

Engine Component Developments - Tribology

ZHIFENG ZHANG, Miba Precision Components (China) Co., Ltd.

Sebastian Kirchhammer, Miba Glitelager Austria GmbH
Emil Bakk, Miba Glitelager Austria GmbH
Oliver Feng, Miba Precision Components (China) Co., Ltd.
Hellen Li, Miba Precision Components (China) Co., Ltd.

ABSTRACT

Combustion engines are in use over hundred years and have been developed and optimized for high efficiency, economy, long life and to achieve also environmental friendliness. Development is still going on, especially with the focus on alternative fuels with their special combustion and chemical characteristics. In consequence bearings need high pressure and surface speed capabilities as well as robustness for dirt, edge loading and different lubrication situations. Certain materials like lead need to be avoid and especially corrosion resistance is needed for certain fuels and lubricants. In consequence a manifold of different bearing types were developed for the different applications which, in some cases make a very high effort in production.

To get all these facts in line with economical solutions a special program to identify the necessary bearing application related capabilities for further investigation in laboratory and to transfer them on bearing test rigs were set up. On-road, off-road, power generation as well as ship propulsion in the power range from 300 kW to several MW have been considered. Existing and new developed bearing types have been selected and tested for the variety of applications to proof their applicability.

In the publication the whole program will be explained, transfer of application related performance request for different engine sizes in different applications, test candidates will be described, test equipment will be shown, and the results will show bearing types and modifications to fulfill all requested specifications and capabilities. Validation and cross reference to field experience will be explained for test program evaluation as well as for the different bearing designs. Upcoming new bearing types will be lined up with existing bearing applications based on key performance indicators to give engine designers the possibility to reference to their own engine experience.

1 INTRODUCTION

For more than a hundred years, the internal combustion engines have been serving for transportation, power and shipping and have an enormous installation base. However, some small size internal combustion engines are being replaced by e-mobilities recently due to CO_2 reduction, and the portion is still growing. Large engines will remain due to their enormous power density, flexibility in different applications and possible green operation based on alternative fuels a main pillar in power generation and shipping. Re-fitting of existing engines gives the opportunity for green operation also for already existing engines.

All the upcoming changes as for power increase, reduction of fuel consumption and environmental demands as alternative fuels will also influence engine components and need certain development to adapt bearing materials and types. Additionally, economic parameters like production processes and economy of scale need to be addressed.

1.1 Environmental regulations, greenhouse gas reduction and engine challenges

In consequence of global warming, greenhouse gas regulations are entering stage and adding CO_2 into emissions. Example EU target: -55% in 2030 and CO_2 neutral for 2050. IMO cares on global shipping and ECA's (emission-controlled areas). China also announced the goal that CO_2 peak by 2030 and CO_2 neutral by 2060. Consequently, further efficiency increases and to cope with CO_2 neutrality alternative fuels based on hydrogen are under consideration. A selection of existing and alternative fuels under consideration for bearing testing are listed in Table 1.

Table 1 Alternative fuels and characteristics

		Reference to MDO			
Fuels	Energy MJ/ltr	Load / Wear	Corrosion	Cavitation	Tank
Hydrogen	8	+++ (knock risk)	+	+++	gas / liquid
Methanol	15,7	++	+	++	liquid
Ammonia	11,3	++	++	+++	gas
SAF	35	-	-	-	liquid

The use of alternative fuels also has an impact on the combustion characteristics in the engine and in fact on the performance of the bearings.

With a low ignition temperature, hydrogen tends to spontaneously ignite on hot surfaces or impurities in the combustion chamber. Due to this, hydrogen incline higher risks for knocking behaviour. Furthermore, hydrogen shows a rapid progression of the flame front.

In the case of ammonia, corrosion resistance can be an important factor in the design of new engines. Due to the highly alkaline nature of ammonia and its tendency to form copper complexes, the selection of materials used in an ammonia-fuelled engine is of the utmost importance.

In addition, all alternative fuels, due to the chemical structure with high hydrogen, generate significantly more water from the combustion, compared to diesel fuel. When the water content is accumulating in the oil to a certain level, the risk for cavitation and tribology will increase.

All engine adaptations for efficiency and new fuels interact with the engine component life and stability. New fuel tank systems and reformers as well as new after-treatment systems are developed and change the engine design and the environment of their components. Since the cranktrain including bearings are one of the core components in the heart of the engine, investigations for safe long-term operations are necessary. To compensate for the negative influences of blow-by, a re-formulation of lubricants may become necessary and will influence bearing tribology and stability. In consequence bearing type development and testing needed to be adapted.

1.2 General approach Bearing type testing

The questions which need to be answered in different levels of testing are shown Figure 1.

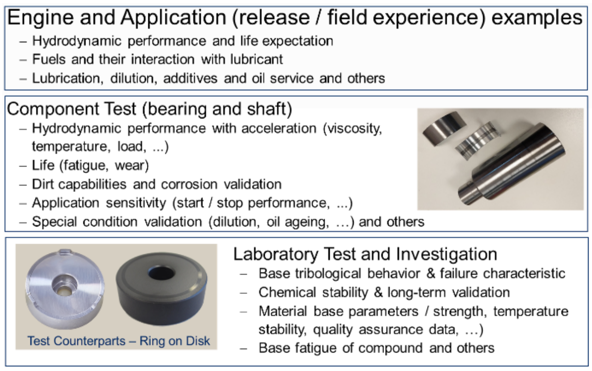


Figure 1 Overview of bearing type test and release levels with corresponding questions to be answered

As you see, bearing type testing and release process is very complex and contain tasks in laboratory for example to evaluate corrosion resistance and long-term stability as well as bearing test rig tasks to simulate for example start up behavior or hydrodynamic behavior or a specific bearing design. For the final release a verification on real engines is necessary to cover all aspects of operation.

Laboratory tests to evaluate tribological behavior, corrosion reactivity and others are standardized to a certain extend. In the Introduction we will focus on the general criteria as specific load and speed. In the specific example of the tri-metal bearing we will show a complete overview including these additional test procedures, test parameters and examples.

A typical hydropulsting test rig to evaluate the hydrodynamic performance is shown in Figure 2.

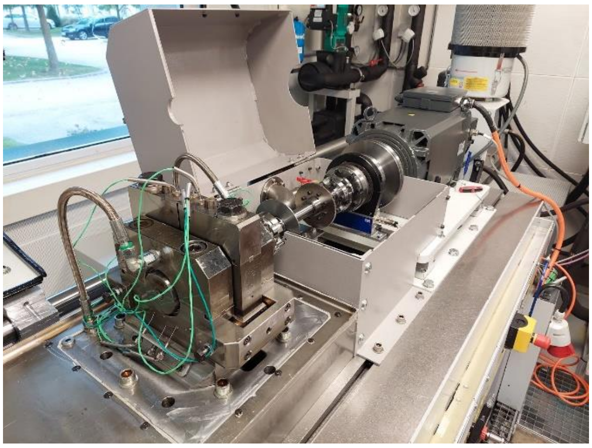


Figure 2 Hydropulsating bearing test rig

1.3 Bearing performance changes and introduction to the bearing families

Following the new engine designs also the new bearing performance demand is changing. Engine families are classified in Medium Speed Engines for power generation and marine application and High power engines. High power 4-stroke engines with automotive conrod design are split additionally in performance and robust. The hydrodynamic performance is lined up with specific unit load and speed, the other characterization is done comparatively in a spider web.

1.3.1 General load and design criteria of different engine sizes and applications

The change of the design criteria “specific unit load” for conrod big end bearings is shown to explain the load increase for bearings over time in Figure 3. To get a clearer picture the graph is split for medium speed engines and high performance engines.

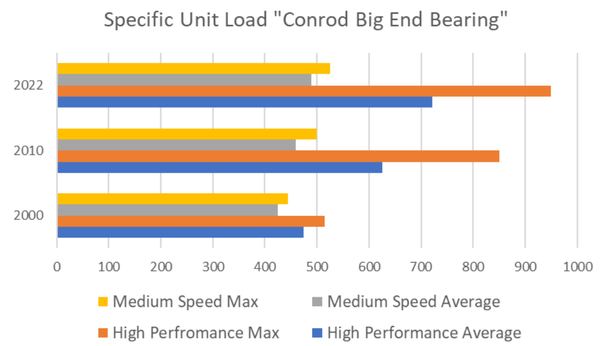


Figure 3 Average and maximum specific unit load of conrod big end bearings over time for High Performance and Medium Speed engines

Medium speed engine load increase is lower but in the same range as the high performance engines some years ago. Bearing sliding speed has changed only moderate and need not to be addressed specifically. But due to necessary fuel flexibility, a high amount of dual fuel engines and retrofit request from customers to cope with environmental requests, many more performance characteristics need to be included in bearing design and validation.

1.3.2 Bearing performance demand for different engine designs

Additional to the long-term standards, several characteristics have been added to reflect the changes in engine design, operation and fuels. The scale of 1 to 5 in Figure 4 represents performance request of the different engine types relatively. 5 indicates highest, 1 indicates lowest demand.

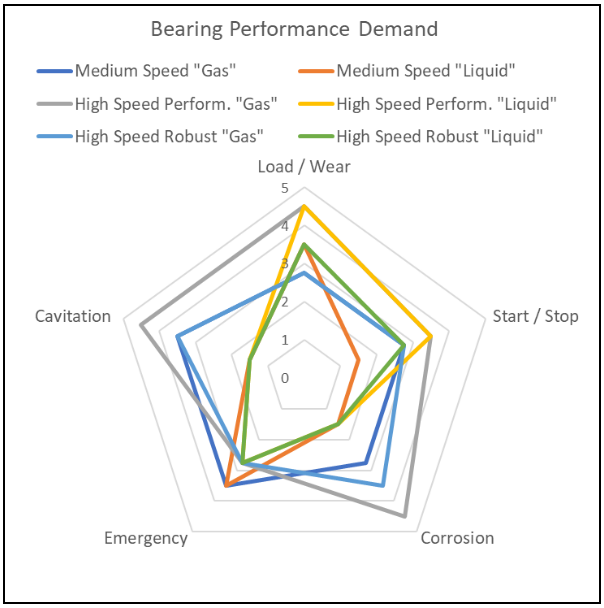


Figure 4 Overview on bearing performance demand for different engine designs and applications

Load and wear demand staid increased according the engine load but corrosion, cavitation become more demanding due to fuel flexibility and start / stop performance reflects changes in engine operation. This performance demand including the upcoming is transferred to the bearing type characteristics and are addressed also in the validation and verification processes. It can also be seen, that certain engine designs need similar performance like the high-performance robust engines and medium speed engines, which gives the opportunity to reduce bearing types and design for economy of scale and in consequence cost reduction.

Relative hydrodynamic performance and their application areas are given in Figure 5 .

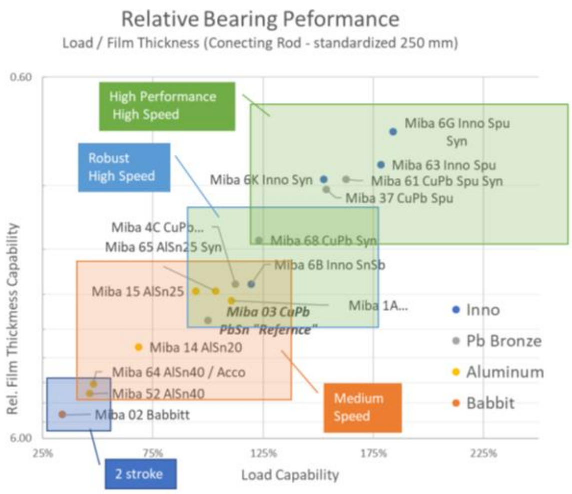


Figure 5 Relative hydrodynamic bearing performance in relation to standard lead bronze tri-metal bearing and typical engine applications

1.3.3 Performance transfer from engine application to the test rig

For every application area and performance characteristic you need a special transfer to laboratory tests and bearing test programs. Engine experience need to be incorporated as well especially when it comes to relative interpretation.

Since this is a very complex task it is shown as an example for the multi purpose Tin base Tri-metal bearing. This tri-metal bearing type was developed to offer a lead free solution and to replace four different tin based surface coatings to reduce production complexity and to achieve economy of scale in the electroplating shop.

1.3.4 Bearing type family characteristics

Referring to above shown performance characteristics existing bearing families have been ranked and lined up in a spider web.

Since all bearings have multiple tasks the multi-layer design gives the possibility to cover different performance characteristics in the different layers. More details can be seen in “Modular Bearing Design”[1] A certain relation between strength and hardness can be identified for lining and overlays. Dirt capabilities are evaluated for sensitivity against small hard particles as dirt shocks or chips to cover metal residuals in assembly. Long term stability especially also referring to the fuel flexibility like corrosion and cavitation needs to be addressed directly in specific laboratory tests. Start / stop, in consequence of new operating approaches need to be addressed in realistic testing scenarios with similar tribology.

Basically, load and wear will decide bearing long term operational performances, start-stop refers to the bearing performances during the mix friction condition such as fast start without pre-lube, emergency relativities bearing capabilities for adaptation and to run in particle involved environment, corrosion is reflecting bearing resistance in aggressive lubrication conditions like acidic oils and, cavitation indicates surface strength against cavitation attack. The cavitation attack will remove the local bearing materials continuously therefore will influence the long term perspectives. An overview over all requested performance criteria for representative examples out of the different bearing families is given in Figure 6 and corresponds with Figure 5.

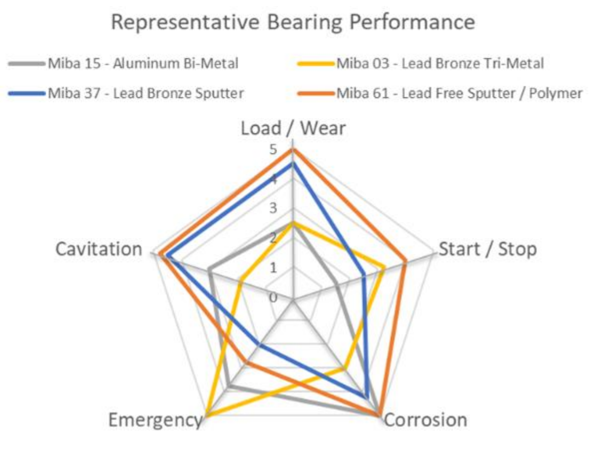


Figure 6 Bearing type family characteristics shown with representative examples

Due to the different performance offerings of the bearing types it can be stated, that the bearing type and material selection need to be done very carefully considering engine performance, application and operation. Nevertheless, a bearing type concentration need to be done for cost consideration and economy of scale. This can only be done if engines are understood adequately and transfer of the performance demand to the validation process is made correctly.

2 VALIDATAION EXAMPLE - TRI-METAL BEARING FOR HIGH SPEED ROBUST AND MEDIUMS SPEED ENGINE

These new bearing types have been developed on basis of several different tin based bearing technologies and electroplating processes. Bronze lining and Ni-intermediate layers have been taken as given. Surface layer has been formulated and the coating process was developed based on BHW and Miba technology.

2.1 Bearing description Miba4B and Miba4C

Miba4C is a new bearing types which already has first positive engine test experiences at the customer side. Figure 7 shows a cross section

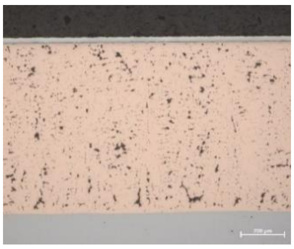


Figure 7 cross section of Miba4C material

As shown a standard build up with steel back, lead bronze lining, intermediate layer of Nickel and the final tin based surface coating was selected. Miba4B, the lead free version is shown in Figure 8.

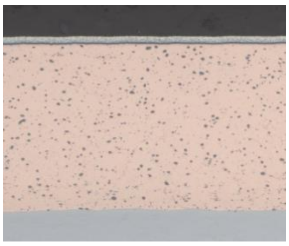


Figure 8 cross section of Miba4B material

Bearing Miba4B is focused on large high speed and medium speed engines. The layer design is similar to Miba4C but with a different lead free lining material.

In order to get adequate tribological properties and to reduce seizure risk when wearing through the overlay into the high strength copper based lining materials, Miba selected Sulfides as tribology improver. Due to the Sulfide phase the welding characteristics to steel (crankshaft) is dramatically reduced. The material offers nearly same tribological properties as high leaded bronze materials in seizure load programs. First engine tests confirmed design targets already in engine operation. The layer design is same as for lead bronze based bearing types.

2.2 Reference Bearings

Miba03 is a traditional bearing material with PbSn electroplating overlay and casted CuPb22Sn lining material and offers a lot of engine and testing experience. Figure 9 shows the respective cross section.

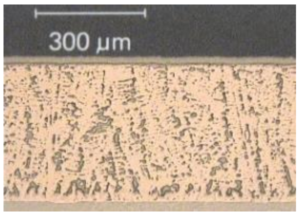


Figure 9 cross section of Miba03 material

It is widely used in High speed and large bore 4-stroke engines with good average load performances and wear resistance. It has extraordinary dirt resistances when the engine cleanness is not given. Corrosion and cavitation resistance is ranked lower due to its sensitivity against sulphur and softness against cavitation attack.

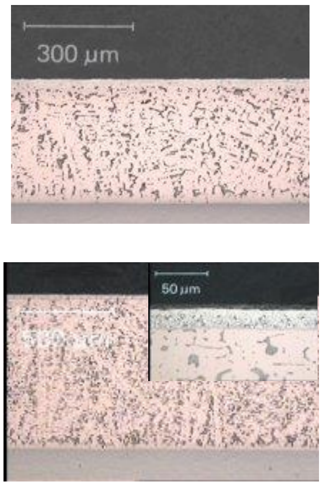


Figure 10 Cross section of Miba37(upper) and Miba61(lower) material

Both Miba37 and Miba61(with Synthec) is AlSn20 Sputter coated bronze bearing with extraordinary bearing load capability and wear resistance. Figure 10 shows the respective cross sections. Besides that, cavitation and corrosion resistance are also in outstanding level due to surface hardness and fine grain. It is widely used in High-Power High-Speed engines as loaded shell in both, conrod and main bearings configurations. Miba61 has both Sputter and Synthec Overlay on the top which is Miba's USP. With this unique design of the overlay. It can offer not only the extraordinary loading capability and wear resistances, but also excellent running in and heavy start stop capabilities. It can contribute especially when low oil viscosity design and helps the cranktrain to gain lower friction losses.

2.3 Bearing requirement of the concerned engines

In general, medium speed engines and high speed engines requirements on the bearing performance are different. The extraordinary load in high speed load shells cannot be delivered by a tri-metal bearing with electroplated overlay so far. Nevertheless, in certain cases of high performance engines a tribological robust counter shell or main bearing design is requested. When analyzing engine operation, the main difference is sliding speed. To cope with these applications also and with the lead free request in future, the program has been modified to represent the additional requirements. The specific engine bearing performance data are compiled in Table 2.

Table 2 bearing performance expectations for different engine applications

Bearing Performance Expectation	High Speed Engine	Medium Speed Engine
Load	< 95 Mpa	< 49 Mpa
Sliding Speed	<18 m/s Average14/s	< 15 m/s Average11m/s
Bearing Life	< 60k hours	< 60k hours
Start-Stop	< 1k times	< 1k times
Dirt resistance	Medium	High
Cavitation resistance	Medium	Medium

The above given values are transferred to the different test programs shown in the next paragraphs.

3 TEST SET UP AND PERFORMANCE CHARACTERISTIC

3.1 Test program setup description

From Table 3 you may find the special designed test programs which are derived from both typical medium speed and high speed engine applications requirement.

Table 3 Characteristics of bearing test and laboratory programs

Test Criterion Engine Type and test condition, time (h)	Purpose	Interpretation
Load / Wear Medium speed 75 MPa, 12 m/sec, 15 h	Wear robustness	Wall thickness cracking
Wear / Fatigue Medium Speed 75 MPa, 12 m/sec , 70h	Long term wear rate	Wall thickness crack propagation
Load / Wear High Speed 75 MPa, 20 m/sec, 15h	Wear robustness	Wall thickness cracking
Seizure Test Step Load, 12m/sec	Tribological robustness	Failure load
Misalignment Medium & High Speed 75 MPa, 12 m/sec, 15 h	Conform-ability	Load distribution Seizure inclination
Continuous dirt Medium & High Speed 75 MPa / 16 m/sec	Dirt sensitivity	Number of shocks
Corrosion Medium & High speed Oil cooking test	Sensitivity Environment oil additives	Layer formation Thickness of reaction layer
Cavitation Medium and High Speed Hardness / Ultrasonic	Material robustness cavitation	Hardness Weight loss

In the listed programs for bearing load and wear capability are prepared as standard. Besides that, application oriented tests[1], such as misalignment, continuous dirt, corrosion and cavitation tests are also performed to mimic the challenges during the engine assembly and operations as close as possible.

3.2 Application related testing results and interpretation

Bending test fatigue of the steel back and lining is evaluated at the beginning to design the appropriate bearing fatigue strength. Then, all other above described tests are performed for the bearing types, produced with production processes close to serial production processes and devices.

3.3 Fatigue-alternate bending test rig results

The alternative bending bi-metal fatigue is evaluated at room temperature according to a Wöhler procedure, the specimen is flat and the test frequency is 25Hz. A crack detection gage is applied to detect the crack happening at the first place and in total 8 samples can be test simultaneously. The device and the instrumentation are shown in Figure 11, base results are given in Figure 12.

Figure 11 Test device and test set up with wire strain gauges

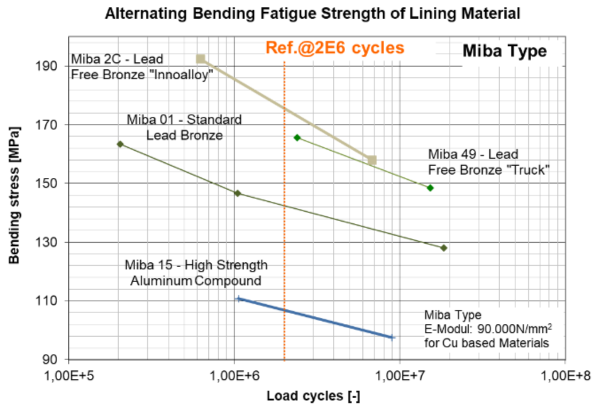


Figure 12 fatigue test result on bronze-based materials

As reference, especially for medium speed engines also Miba 15 is shown as reference. From the test result as 2 shown that we can conclude that:

1. Traditional lead based copper material CuPb22Sn2 (Miba01) has advantages in terms of lifetime against AlSn25 (Miba 15)
2. Miba new generation of lead free material INNOalloy (Miba2C) has even stronger fatigue strength compared to traditional leaded bronze material and is in similar range as the existing high strength lining (Miba49) used in truck applications.

3.3.1 Wear test result – break in

The wear test parameters were differentiated for high load and high speed and medium load medium speed engines, please refer to Table 4 for the different parameter settings for the applications.

Table 4 testing parameters setting for different applications

Testing Parameters	High Speed Engines	Medium Speed Engines
Unit load	75Mpa	75Mpa
Sliding speed	20m/s	12m/s
Oil specification	SAE10	SAE10

The unit load is 75Mpa, bearing surface sliding speed is 12m/s, oil specification is SAE10 and the oil inlet temperature is 110 °C. The wear performance and load capability are measured in the bearing main loaded area. And the results are calculated as the average value at the bearing edges and the center of the bearing main loaded area.

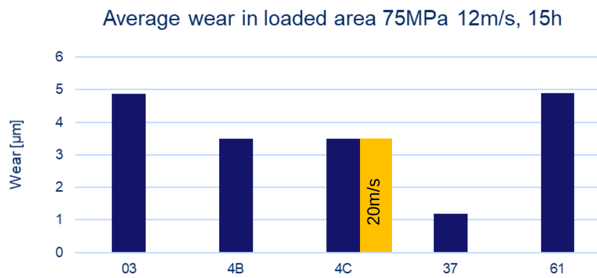


Figure 13 Wear test rig result break in

As testing result Figure 13 shows that Miba4C material shows an improved wear resistance against traditional Miba03 electroplated bearing. Miba37 is best of the performer in terms of the wear, Miba61 has certain fluctuation because of the Synthec overlay on the top is designed as running in layer therefore may have wear rate variations from test to test. And in general, it is believed that the first 15 hours is the typical period for the bearing material break in.

When the Miba4C is testing under 75Mpa with 20m/s sliding speed, we see that in orange column as Figure 13 shown that it has the comparable wear resistance capability compared to 12m/s.

3.3.2 Wear test rig result- long term

The test procedure, loads and speed, as well as the oil condition remains as the same as the short-term wear test. However, the test endurance is extended to 55 hours after the break in total with intermediate inspection after 15 hours to separate long term wear rate from break in wear. Long term wear is then shown in Figure 14 for the different bearing types.

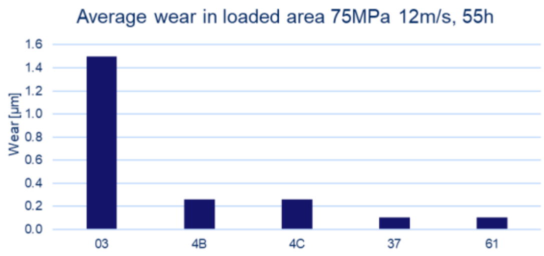


Figure 14 wear test results – long term

Both of Miba4C and Miba4B has significant reduction on the wear rate and shows excellent long-term wear resistance characteristics compared to traditional electroplating bearing Miba03. Miba4C is very close to Miba61 in terms of wear rate. Of course, the Miba61 has the same level wear rate compared to Miba37 after the Synthec overlay is gone.

3.3.3 Start Stop test rig result

This program is designed to verify bearing materials behavior under mix friction or even boundary lubrication conditions. Start up procedure from a mid size high speed, high performance engine was modelled, therefore the test look quite different to automotive application test. Result interpretation is done via the average wear rate at bearing ends and centerline position of the main loaded area. Test unit load is continuously set to 2.4Mpa and the sliding speed ramps under given load from 0 to 2m/s within 1800 cycles. The oil in use is SAE10 with an inlet temperature of 120°C.

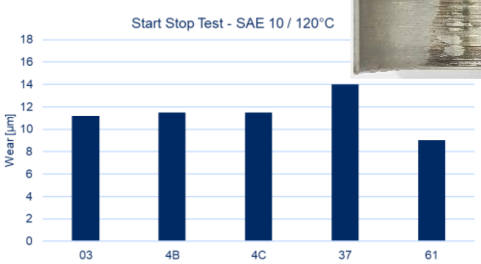


Figure 15 start stop test rig result and bearing appearance

All tri-metal bearings showed very similar performance as Figure 15 tells us. Although smearing can be detected on the shown tri-metal picture, but the bearing is full functional. In comparison Miba 37, the sputter bearing shows a slightly higher wear rate due to it AlSn20 overlay which tends to release tin under mixed friction conditions. An additional polymer layer applied as emergency lubricant in Miba61 improves the sputter bearing to the best bearing type available.

3.3.4 Static Seizure Load test rig result

In this test program, the bearing seizure load will be identified in case of high temperature and limited oil supply to the main loaded area. The oil is SAE10 and the oil inlet temperature is 120°C to accelerate the test. The oil supplement volume is 1,75L/min, sliding speed is 12m/s in which high energy in introduced and the bearing is loaded starting from 2,85Mpa until seizure happens.

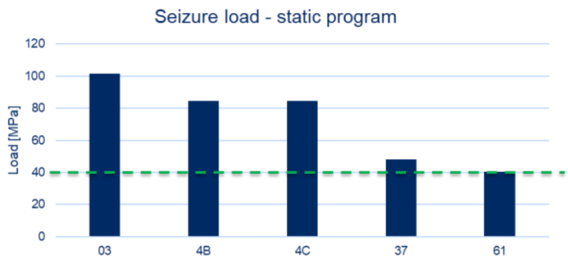


Figure 16 static seizure load test rig result

All the bearings can survive from 40Mpa which is enough for the standard application needs as indicated by Figure 16. All the electroplated bearing materials, Miba03, Miba4C and Miba4B show excellent seizure resistance. Miba37 and Miba61 has relative lower seizure resistance due to it's hard overlay and of course please notice that the oil supplement to the bearing loaded area is limited due to static load characteristics.

3.3.5 Dynamic Seizure Load test rig result

The dynamic load step program is to identify the seizure load in case of high temperature. The oil is SAE10 and the oil inlet temperature is 120°C to accelerate the test. The oil supplement volume is 1,75L/min, sliding speed is 12m/s in which high energy is introduced and the bearing is loaded starting from 2,85Mpa with 50Hz dynamic load increasing until seizure happens.

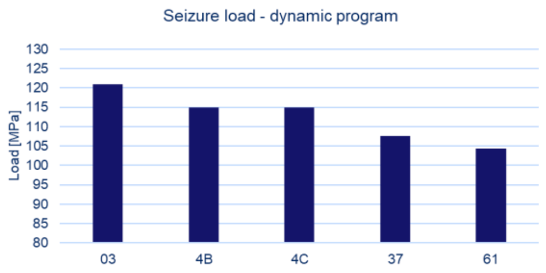


Figure 17 Dynamic seizure load test rig result

All the bearings can survive from 80Mpa which is enough for the standard application needs. All the bearing materials show performance significantly above the application needs as Figure 17 shown.

3.3.6 Dirt resistance test rig result

This test program is designed to identify the bearing material's robustness against hard particle shocks. The test bearing has a diameter of 48 mm and a width of 12mm. 75 MPa specific unit load at 16m/sec is applied in an environment with SAE10 oil at 110°C. The hard silicate particles[1] are shot directly in the oil feed line in via a revolving device shown in Figure 18 together with some dirt example.

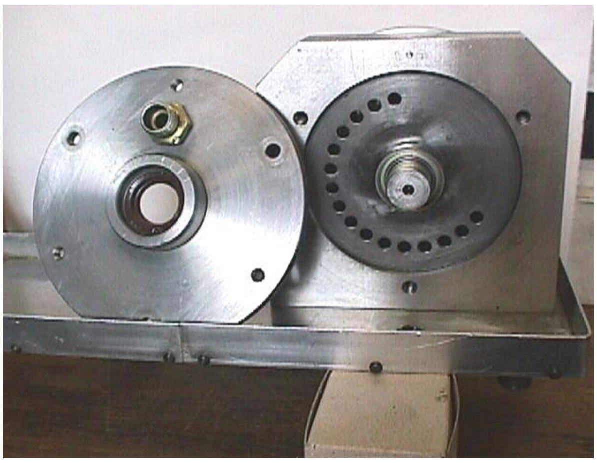


Figure 18 Dirt revolver – dirt (Silicates with extreme hardness) is filled in the chambers according specification starting in the second chamber.

The test is segmented in three parts:

- ➔ A continuous test part with particles of max. 25µm. If the bearing pass this first part the bearing is suitable to run in an engine with standard cleanliness. Particles are kept in the oil system for the whole test procedure.
- ➔ In the second part robustness against particles smaller than the clearance (max. size 40µm) is tested. An increasing amount of dirt starting with 0,03g up to 0,15 g is applied in 5 shock. High robustness for dirt coming from combustion or cleaning residuals can be stated for the bearing failing during this test sequence.
- ➔ Extreme robustness against mechanical damages by particles is tested in part 3. Particle size with 80µm is much bigger than the bearing clearance and will scratch into overlay and lining.

The bearing needs not only a good local resistance but also an extreme tribological behavior to withstand. 8 shocks from 0,18 g to 0,39 g are applied.

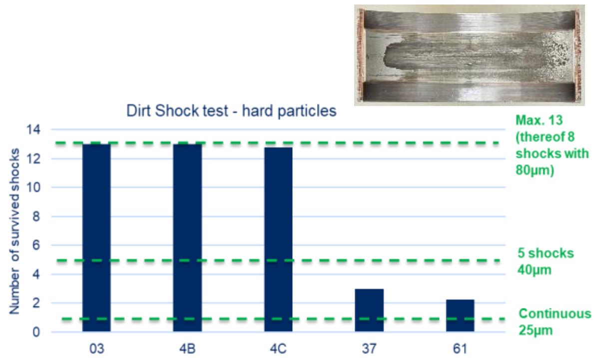


Figure 19 dirt resistance test rig result

The test result shown by Figure 19 gives the indication that Miba4C, Miba4B and Miba03 have the best performance against the dirt, Miba03 material survived from all the 13 shocks and Miba4C, Miba4B is almost there. Miba37 and Miba61 are above 2 and they are capable for the standard application requirement. In the high speed and medium speed applications, that quite often the engines are failed by insufficient cleanness at the early stage of the operation due to difficulties of burrs removal and clean during the machining and assembly. Miba4C gives the bearing an excellent resistance and robustness on the deburrs therefore has better chance to survive from the cleanness issues.

3.3.7 Misalignment / conformability test rig result

Local overloading is quite frequently happening during the engine running in phase when there is misalignment of the housing or pin or blending of the pin or the deformation of the housing during the firing. The bearing system can either adpapt and distribute the load on a wider area quickly or fail by seizure. Our misalignment test is designed to identify this adaptation capabilities in case of loacal overloading. Especially the sensitivity against edge loading is shown comparatively for different bearing types by the survival rate. Additionally overlay life under the extraordinary load conditions is indicated by average runtime under full load and shows the long term operational risk.

An inclination of 40 µm within bearing length of 34 mm is applied on the bearing running under 75Mpa unit load and 12m/s sliding speed. SAE10 oil and the inlet temperature of 110°C reduce the oil film thickness in addition and accelerate the test. Bearing appearance after test is shown in figure in 18 and shows the local behavior of the bearing.

Miba 03 Miba 4C Miba 6K

Figure 20 Bearing appearance after test

The bearing appearance after test as Figure 20 show severe edge loading and how bearings cope with this extraordinary load condition. The standard tri-metal bearing wear in a more limited area in comparison to the new Miba4C, which is also indicated by a lower survival rate. The polymer bearing cope with extraordinary robustness and load capability which is shown by the reduced wear and adapted area. Results are summaries in Figure 21.

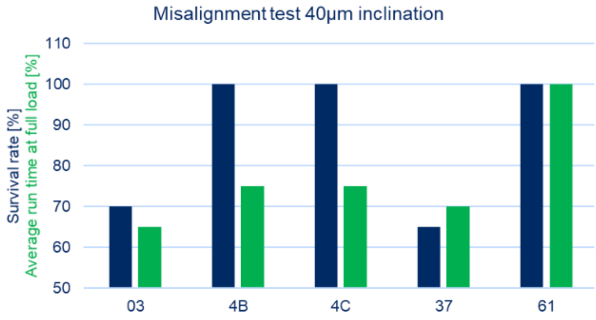


Figure 21 misalignment test rig result

Bearing type Miba4B, Miba4C and Miba61 adapt quickly by local wear and all bearings survived. Miba37 and Miba03 showed less robustness against edge loading. If the sputter bearing Miba 37 is optimized with a Polymer running in layer conformability is on highest level and long term performance becomes extraordinary since the sputter layer is not worn off.

3.3.8 Corrosion and Cavitation test rig result

The static oil cooking test is a procedure to verify the oil-material-compatibility of various bearing materials. It was developed in times when HFO entered the market and afterwards it was adapted to represents engine operation with special gaseous fuels. Additional tests are initiated and developed now to represent the new alternative fuels.

For the test representing medium speed and lower loaded high speed engines, the reactions between the bearing materials and additives used in gas engine oils are observed. For an accelerated test result, the conditions are chosen to be 160°C for 150 hours. To determine the corrosion behavior, the content of bounded sulfur on the bearing surface is measured and related to the bearing surface by using SEM EDX.

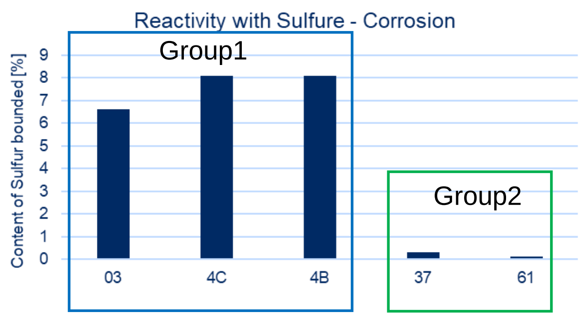


Figure 22 Corrosion result relatively

From Figure 22 we can see 2 specific groups of bearing types engaged in Sulfur reaction. The electroplated overlays of Tri-metal bearings

(Group1) Miba 03, Miba 4B and Miba 4C, which need copper to improve wear stability show more reactivity. Additives containing sulfur mainly react with copper by forming CuS on the bearing surface. Field experience with given Tin base overlays have already confirmed good performance when it comes to wear – corrosion in medium speed engines.

The overlay compositions for Sputter as Miba 37 and Polymer bearings like Miba 61 show nearly no reactivity.

The cavitation test occurs on material surfaces that are exposed to intense ultrasonic cavitation. Please refer to "New developed and standard bearing types focused on gas engines" [3]for the testing details. This is a fast method of measuring the erosion resistance of a material or coating to intense stress and other erosion factors. By operating conditions of 200W and 10 minutes it provides a quantitative measurement of weight loss.

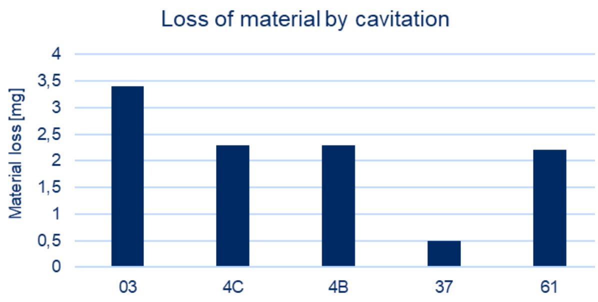


Figure 23 Cavitation test result

Based on test result Figure 23, Miba37 shows very low cavitation due to its high hardness of the sputtered AlSn20 overlay. Miba03, Miba4B and Miba4C have higher material loss in the cavitation test, caused by the reduced hardness, compared to Miba37. The polymer layer of Miba61 wears out after a short time in the test, the wear slows down considerably in the case of the sputtered layer below.

3.3.9 Oil Material Compatibility Testing

With the accelerated transition from conventional diesel engines to alternative fuel systems, it is very important for a bearing solution provider to keep an eye on the entire engine system from combustion to the use of engine oil types.

Especially the choice of engine oil can play a decisive role in the longevity and performance of a plain bearing. The selection of the wrong additive packages on the one hand and the corresponding oil ageing with alternative fuels on the other hand (also in connection with the combustion products and the blow-by of unburned fuel), can influence the service life of the bearing. Therefore, it is of utmost importance to select the right oil material combinations for the application.

To discover and quantify possible chemical interactions between the bearing materials used and the engine oils, in new and aged condition, special test methods based on static oil material compatibility tests were developed. These are based on a combination of the ASTM D130 and VDMA 24570 standards. For the testing procedure material stripes (pure metals and bearing material compounds) are immersed in the new or aged oil at temperatures between 60°C up to 180°C. The used coupons are weighed in constant time intervals to evaluate the weight loss and the optical appearance as indicator of sensitivities to corrosion.

In order to understand the processes of oil ageing in the engine and its effects on the bearing material, Miba is currently designing a test setup for artificial oil ageing. For this purpose, oil samples are aged under the influence of different combustion products and alternative fuels. In combination with the previously described static oil material compatibility tests and trials on the tribometer, the effects of different conditions and fuels on the bearing performance can be evaluated.

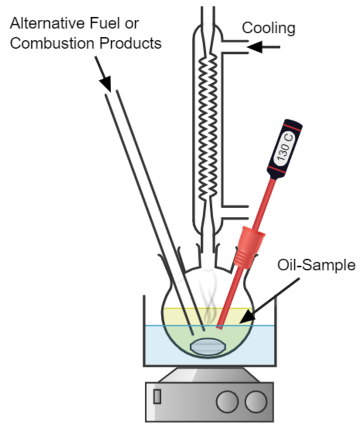


Figure 24 Schematic representation of artificial aging on a laboratory scale

The main goal of the oil ageing and oil material compatibility tests is to reproduce results from the field in a laboratory scale and to bring these findings into the test rigs, together with external partners and universities. This can help to develop new materials and technologies for future applications.

3.3.10 Result and interpretation

A result interpretation is performed as overview based on the spider web diagram as overview in Figure 25. Please note, that the applications rank from medium speed to high speed high performance engines and may differ, when looking only into one application spectrum.

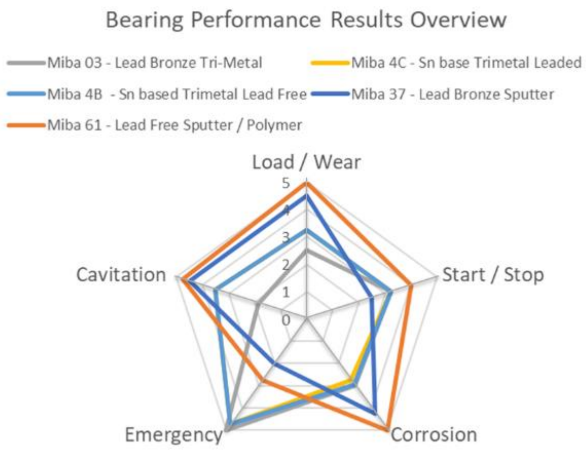


Figure 25 Bearing type families characteristics

The difference between tri-metal and high performing sputter bearing can be identified easily. Tri - metal bearings with extraordinary good tribological performance for misalignment, dirt and starvation conditions competes with extraordinary hydrodynamic performance of sputter bearings. In many cases of the large bore engines when the engine cleanness or bearing adjacent parts quality is not given, therefore the bearing emergency character really matters. As a consequence, tri-metal bearings with higher tribological performances in terms of robustness and operation safety against the particles, misalignment and oil starvation are much more preferred instead of the sputter bearings. In addition, sputter bearings have size limitations due to constrains from the coating machinery. Nevertheless, the new tri – metal bearings have extended their application area by improving load and cavitation against standard tri – metal lead bronze bearing and do not have size limitations.

4 FIELD EXPERIENCES

The Miba4C bearing material already has lots of success running experiences in both high speed and medium speed engines with more than thousands of hours. An example of a medium speed engine after 3,000 hours of operation is given in Figure 26.

Figure 26 overview of the Miba4C in one of the customer engines after 3000 hours operation in the field

The bearing is in perfect condition with smoothening in the main loaded area and no sign of material fatigue and excessive wear is observed.

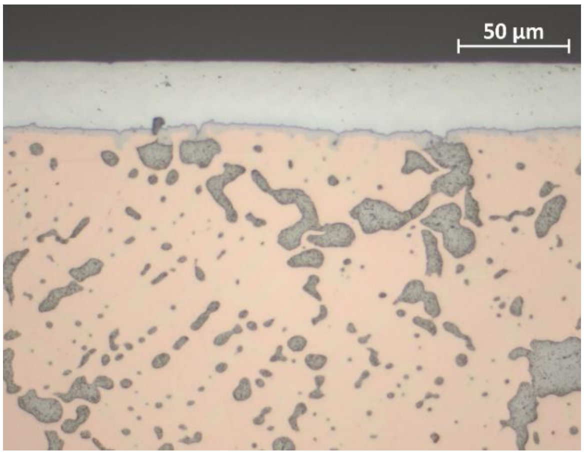
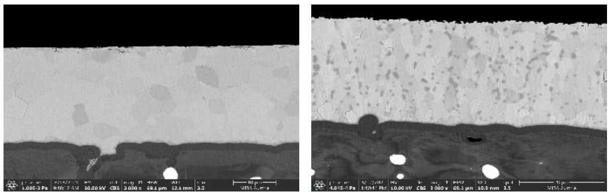


Figure 27 cross section at the main loaded area

When looking deeper by metallurgical cross section shown in Figure 27, perfect microstructure on both electroplating overlay and lining material is found, no sign of Sn depletion and lead aggregation can be found, meanwhile the remaining thickness of the overlay is still in good value and we see that the bearing wear resistance is strong.

A deeper insight view into the Miba4C overlay structure and condition is given in Figure 28. Based on a cross section prepared by our adapted ION beam milling device further details become visible.



Loaded Area Reference Area

Figure 28 Ion beam polishing cross section investigation

The reference area shows a structure similar to a new one. When looking on the loaded area we see a homogenized and smoothened structure with improved tribological properties and good wear resistance.

5 SUMMARY AND OUTLOOK

The Miba inhouse bearing test is a specialized bearing performance validation approach for different applications by recognizing the application demands and transferring the demands to bearing rig test parameters and settings.

During the new bearing material development, in considering the bearing type portfolio management, that to use one bearing material type to serve more than one engine application is possible. With the newly developed Miba 4B and Miba4C bearing material, we are now in a good position from one hand to reduce the portfolio complexity and increase the economical scale and consequently reduce the cost, which means that Miba03, MibaZ1, MibaT6, BHW87 will be replaced by Miba4C, from another hand Miba4C can be used in both high speed robust application and medium speed applications. And the influences on bearing by the new or alternative fuels, such as ammonia, methanol, H_2, etc., is very well combined.

Besides that, local production of the Miba4C with the SnSbCu electroplating overlay in Miba bearing plant at Suzhou industrial park, China is already planned. Once it is fully implemented, we are more flexible to serve the local customers in engine development or special requirements.

At last but not the least, it is an upgrading approach therefore the test rig parameters, settings are always adapting to the new demands from the technology and the market.

As conclusion it can be drawn that:

- Application related bearing testing is representing different applications with their characteristics
- One Bearing type can serve more than one engine application when considering it from the beginning and develop accordingly
- New/alternative fuels need more attention in future. Especially bearing long term stability may become more important when considering cavitation and corrosion. Additional investigation in alignment with field experience will become necessary

6 REFERENCES AND BIBLIOGRAPHY

[1] Aufischer, R.2013.Modular Bearing Design to Cope with the New Engine Designs Demanding High Performance, Lead Free Solutions and Robustness, ICEF 2013, Dearborn, Michigan, USA 2013

[2] Forstner, C and Mairhofer, G. 2007. Applciation oriented bearing testing, CIMAC 2007, Vienna, 246

[3] Rumpf, T.2001.New developed and Standard Bearing Types Focussed on Gas Engines, CIMAC 2001