Bottom Bracket Bearing Fatigue & Efficiency Test

Comparing Enduro Bearings XD15, Maxhit™ & ABEC 3 to six leading brands

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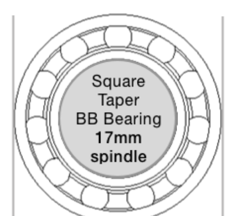
A History of Problem Solving

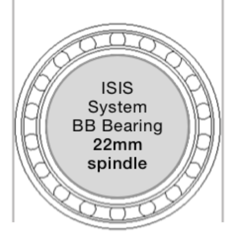
Founded in 1996, Enduro Bearings has designed and manufactured bicycle bearings for nearly 30 years. Co-founder, Matt Harvey, leads the company's cycling division. Matt has a Bachelor's degree in Mechanical Design and previously worked in product management and development at White Industries, Gary Fisher Mountain Bikes and Bianchi.

In 1997, Enduro introduced its first bearing innovation: MAX full-compliment suspension pivot bearings, now widely considered as the industry standard. Enduro continues to innovate and expand its offerings to include over 1,000 hub, headset, bottom bracket, derailleur pulley bearings and components. The company invented Torqtite, which inspired dozens of thread-together solutions for noisy, press-fit bottom brackets. Twelve years ago, Enduro developed the first of two "forever" products, XD15 ceramic-hybrid bicycle bearings. In 2021, a second lifetime warranty product hit the market: the patented, all-440C stainless Maxhit™ headsets and bottom brackets. Now a global enterprise, Enduro Bearings supplies hundreds of OEM manufacturers and thousands of retailers worldwide. Millions of cyclists pedal bikes with Enduro Bearings inside.

Modern Bottom Bracket Bearing Failures & Fixes

In the late 1990s, in the interest of improved pedaling efficiency, industry leader Shimano introduced larger diameter 22mm hollow, splined crankset spindles. Unfortunately, the bottom bracket shell inner diameter held tight at 35mm – a specification introduced in the 1800s to accommodate smaller 17mm square taper spindles.





Competitive drivetrain manufacturers countered Shimano with an industry-wide adoption of the ISIS (International Splined Interface Standard) BB System, which also utilized a 22mm (or 21.5mm) spindle. With less 'bearing space' available in the 35mm BB shell (drawing to the right), fragile bearings with thin races and significantly smaller 2mm-2.5mm bearing balls were specified.

Soon after introduction, ISIS and Shimano bottom bracket bearings began failing quickly and in large numbers. This is when Matt Harvey had an idea and went to work.

Building the Test Machine

An improved ISIS bearing solution had to be developed quickly. This required test equipment to dramatically shorten the R&D timeline. Matt Harvey soon realized that cycling-specific test equipment did not exist, so he designed and built a bike bearing test machine. Within a few months *Max Tester*, the bearing test machine, was successfully simulating the high radial and axial loads with rotational speeds common to bicycle bottom bracket bearings. This drastically reduced the analysis time from many months of field testing to a couple of weeks of amplified lab testing.

Soon after, Enduro Bearings designed, tested and introduced a unique ISIS compatible double-row radial bearing with durability equal to 17mm square taper spindle designs. By the mid-2000s, the market abandoned the ISIS BB standard in favor of an outboard bearing design that reintroduced larger ball bearings with thicker races to better support the crankset.

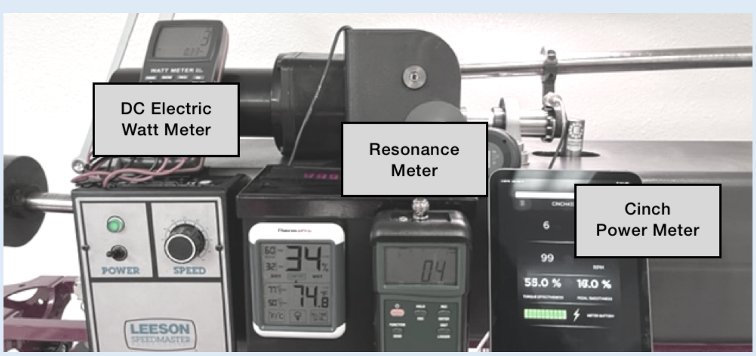
As the cycling industry continued to develop bottom bracket variants, Enduro has rapidly responded with reliable, efficient, longer lasting bearing solutions using superior steels and ceramics along with larger ball diameters and deeper groove races. One of many examples is the invention of MR 2437 bearings to improve on Shimano's outboard 6805 bearings with the "plastic top hat".

Max Tester II: Adding Energy (Watts) and Vibration Tracking to Multi-Direction Load Testing

In advance of the bottom bracket bearing test shared herein, Enduro refreshed and upgraded *Max Tester* with three data measuring devices. Not only can the machine comparatively test bearings for longevity and failure, Enduro's test machine can now measure bearing efficiency over time through wattage as well as detect bearing wear and deterioration through vibration testing.

Vibration testing is common practice in aviation, automotive and other industries. A new smooth bearing exhibits a reading of 0.5 – 0.8 mm/second (including test machine interference). When a bearing begins to deteriorate, usually triggered by internal race galling, vibration readings will double or triple. A reading in excess of 2 mm/second is an early warning for total bearing failure.

- Energy (watts) data for each bottom bracket tested are included in the results on page 4.
- Vibration data are not included as the resonance meter was recently added. However, the early data indicates that as vibration increases, wattage numbers also increase.



Watts in the Real World

Ball bearings are extremely efficient with a very low coefficient of friction. In cycling, there are many enhanced claims regarding bearing efficiency and watts saved. In reality, a new well-made bottom bracket bearing assembly only uses one-half watt. A low quality assembly doubles drag to one full watt. The largest wattage drain in a clean drivetrain is the chain at approximately five watts.

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Amplified Testing: Larger Loads Speed-up Testing and Improve Accuracy

To gather precise, accurate data, amplifying test parameters are common practice in aviation, automotive and many other industries. In normal cycling conditions, a pro athlete weighing 68 kg. / 150 lbs. is loading and unloading a pair of radial bottom bracket bearings at 100 RPM and averaging 250 watts. Enduro's test protocol involves just one bottom bracket bearing at nearly twice the power input and three times the weight. Short testing times are indeed beneficial. Another benefit of amplified testing is the ability to consistently collect data within the 'measurable zone' of a power meter. For example, commercially available watt power meters cannot detect differences less than one watt.

Field Testing versus Machine Testing: both matter

In 2011, after in-house machine and shorter duration field testing, Enduro introduced the world's first XD15 ceramic-hybrid bottom bracket bearing and set out to prove that its bearing design philosophy and use of superior materials would result in a "forever" bicycle bearing.

The most valid testing is long term on bikes in the real world, which can take years to complete. In 2011, we installed XD15 bottom brackets on a handful of professional riders' bikes – with no failures. One field tester, a former professional on the Webcor Cycling Team, still rides mega miles in all types of weather on a 2011 race bike with the same XD15 BB. With 60k miles on the books, his XD15 bottom bracket has never been serviced.

Possibly the most surprising XD15 test report was written by James Huang for Bike Radar in 2013. After a year-plus of purposeful abuse, James stated, *"As if that weren't demanding enough, we ran the entirety of the test with all of the seals removed. Despite the fact that we could readily see the fully exposed, naked ball bearings, the XD15 merely laughed it off, spinning as smoothly after months of intentional abuse as it did when new, even with no lubricant whatsoever aside from pulverized sand and grit."*

2021-23 Amplified Bottom Bracket Bearing Fatigue & Efficiency Test

Fast forward to 2021 and déjà vu all over again. Spindle diameters have increased from 22mm to 24mm, 29mm and 30mm, prompting bearing and component manufacturers to revert to the same small ball sizes found in the failure prone ISIS System.

Needing to test its promising but yet unproven all-440C Maxhit integrated assembly bottom brackets, Enduro developed the following protocols for an amplified bottom bracket fatigue test.

Test Overview & Protocols

After 15-plus years of comparing various machine testing protocols and results with real world bicycle bearing deterioration timelines and failures, Matt Harvey determined the following machine testing methods to be the most appropriate and accurate for Enduro Bearings product development.

This test began in September 2021 and concluded in March 2023. Testing hours were Monday through Friday, 9am to 5pm. All testing was supervised by Matt Harvey either in-person or via video recording. The test machine resides in a closed, temperature controlled room. All test bearings were stored in a clean but not sterile environment between test sessions.

All test hours were run at 100 RPM or 6,000 cycles-per-hour. After the warm-up period described below, a 30mm "Cinch" Power Meter spindle is mated to the test machine shaft for gathering loaded bearing watt measurements at the intervals shared in the results chart on page four. In every instance, one bottom bracket bearing (not two) rotated under 82 kg. / 180 lbs. radial and 27 kg. / 60 lbs. thrust loads for a total axial load of 109 kg. / 240 lbs. This equates to a 218 kg. / 480 lbs. rider pushing a consistent 600 power watts.

The test did not include sinusoidal testing with varying forces. A constant pressure was applied, as the ball bearings were spinning and loaded in either scenario. As in the aviation industry, amplifying a test and overstressing the bearing is a standard procedure to produce more consistent and measurable results.

Warm-up Period

Without a bottom bracket attached and zero load applied, the DC electric watt meter attached to the test machine shaft read 2-3 watts. With a new bottom bracket test bearing installed onto the test machine shaft and under light axial load, the shaft reading increased to 3-4 watts. After a twenty minute warm-up, all new test bearings, without exception, measured a stable 3 watts at the test machine shaft.

Bearing Test Data Acquisition

With test protocols established, in every instance for each test bearing and at every data capture interval, the following steps were repeated:

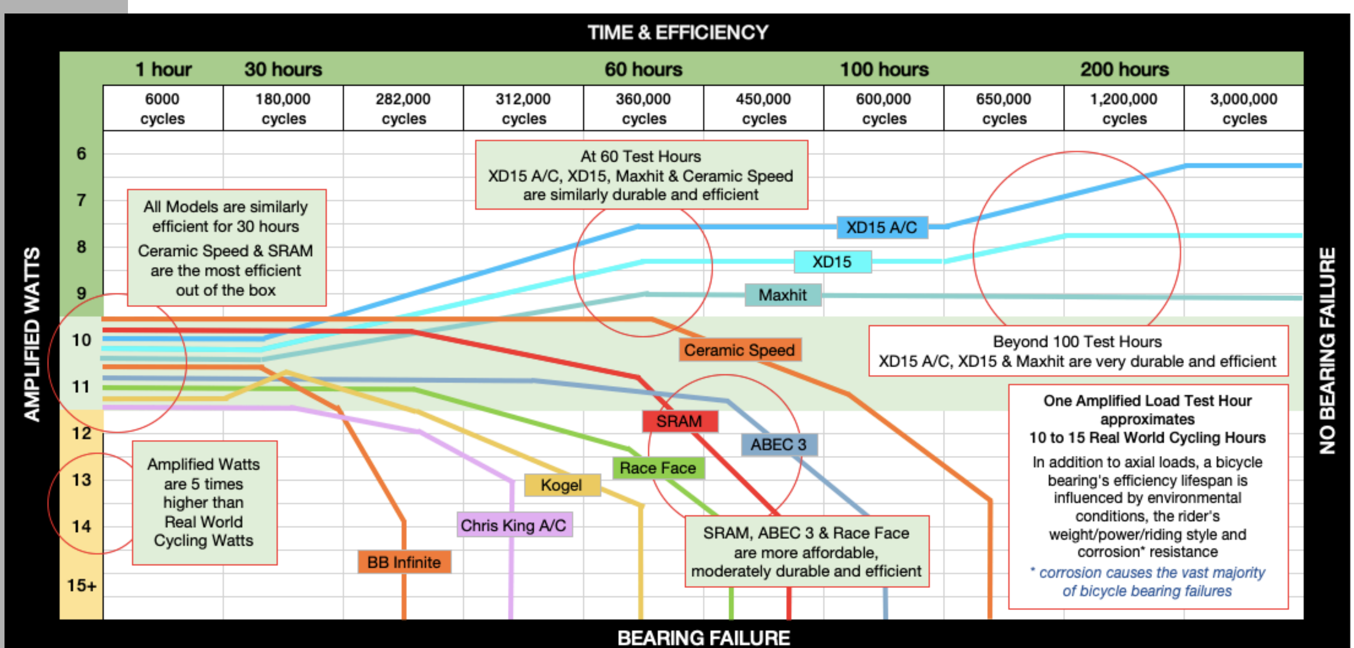
- Test bearings and room temperature were warmed to 20C / 68F.
- A 2-hour test machine warm-up period was honored.
- The DC electric and Cinch power meter wattage was stabilized at 2 watts each.
- Test bearings rotated at 100 RPM for 20 minutes under light radial and thrust loads.
- Test bearings were fully loaded, rotating at 100 RPM for 10 minutes prior to capturing the data.

Test Mules: 4 Enduro & 6 Competitor BB Bearing Assemblies

An assembly is defined as the outer, splined aluminum cup with bottom bracket bearing pressed-in or an integrated bearing assembly such as Enduro Maxhit. The test included two unaltered samples of each bearing assembly, ordered from a bicycle parts and accessories distributor in original packaging. Testing multiple samples would require many years rather than 18 months.

BB Specification	Maker & Model	Ball Diameter	Ball Material	Race Material	Retail Price
BSA threaded shell 30mm spindle diameter	Enduro Maxhit	4.760 mm	440C Stainless	440C Stainless	$179
	Enduro XD15 A/C	3.970 mm	Ceramic	XD15 Stainless	$299
	Enduro XD15	3.970 mm	Ceramic	XD15 Stainless	OEM only
	Enduro ABEC 3	3.970 mm	Chromium Steel	Chromium Steel	OEM only
radial type bearings with two exceptions: Enduro XD15 A/C Chris King A/C (15-degree angular contact)	BB Infinite	3.175 mm	Ceramic	Chromium Steel	$220
	Ceramic Speed	3.175 mm	Ceramic	Chromium Steel	$359
	Chris King	3.175 mm	440C Stainless	440C Stainless	$178
	Kogel	3.175 mm	Ceramic	Chromium Steel	$260
	Race Face	3.175 mm	Chromium Steel	Chromium Steel	$60
	SRAM	2.750 mm	Chromium Steel	Chromium Steel	$41

Test Results & Observations



- All bearings initially performed slightly better after a ‘seals and grease’ break-in period.
- After the break-in period, depending on the seal design and the amount of grease fill, all bearings preformed equally well, averaging 10 to 11 amplified watts for the first 30 test hours.
- Soon after wattage numbers increased, bearings became noisy under machine load. They would spin rough with more resistance in your hand, indicating spalling to galling deterioration.
- For expanded observations on each of the bottom bracket bearings included in this test, scroll to Addendum 1 below.
- The results chart offers additional insights, including how corrosion impacts bearing lifespan.

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Conclusions

1. **Bearing assemblies with fewer, larger bearing balls perform better and last longer than bearing assemblies with smaller bearing balls in greater numbers.**

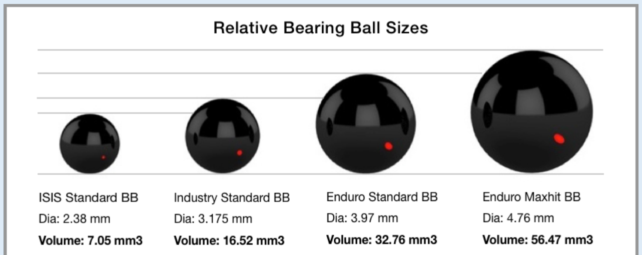
   In all cases, the matching of larger diameter bearing balls with deep groove bearing races produced desired improvements in efficiency (watts) and durability (cycles).

   At a given RPM, larger balls roll slower than the smaller balls; half the speed in some bearing sizes. Fewer, larger balls spread the load better due to an aggregate contact patch area that is greater than the aggregate contact patch provided by smaller balls in greater numbers. This effect is called Hertzian force. Less energy or wattage was needed to rotate Maxhit and XD15 bearings under load compared to the other models using industry standard bearings with smaller balls and shallower races.

Hertzian forces, in this case, are the reaction of a bearing ball meeting a bearing race under load resulting in a wave.

As the balls roll along the race groove, at a micro level, the ball deforms the bearing race, causing a wave in front of the rotating ball.

Fewer larger balls mitigate this reaction as their combined surface contact patch is larger than smaller balls in greater numbers. This translates to less power required to spin at a given RPM and longer bearing life.



red dots illustrate contact patch size
a larger contact patch reduces Herztian Force to extend bearing life

2. **Bearing designs that harmonize material choices last longer. Materials that perform well independently can, when combined in a bearing assembly, lead to premature bearing wear and failure.**

   Combining premium quality ceramic balls with a Nitrogen-infused stainless steel bearing race outperformed quality ceramic balls rolling in chromium steel bearing races in both key measures: rolling efficiency and longevity.

   440C Stainless Steel is known for its corrosion resistance, resiliency, and relative softness. Under load, this metal is prone to premature wear when paired with smaller 440C bearing balls. When paired with larger 440C bearing balls, efficiency and durability improve dramatically.

3. **Only the bearing designs that combine the attributes of conclusions #1 and #2 completed 3,000,000 cycles as good as or better than new. Some other models tested began to deteriorate at 150,000 cycles, with all models losing efficiency no later than 360,000 cycles.**

   Optimizing bicycle bearing design for performance and durability is not one thing, it is many things. It requires a thorough understanding of multi-directional cycling loads, application-specific material choices (balls, races, seals and grease), manufacturing rigor and quality control.

Peer Review

Test machine design and operation, test protocols, test results and conclusions were critiqued, edited and accepted by Todd Chavanne. Mr. Chavanne has a Bachelor of Science degree in Aerospace Engineering and a Masters of Engineering degree in Space Operations. Currently employed by Sullivan Steel Service, Todd brings more than twenty years of practical experience to this project.

Full disclosure: Sullivan Steel Service is an Enduro Bearings supplier

Enduro Product Solutions

Beginning in 1997 with MAX suspension bearings, Enduro bicycle bearings have included larger bearing balls nested in deep grooves. XD15 bottom brackets use 3.97 mm ceramic bearing balls and Maxhit BBs use 4.76 mm 440C stainless balls. Both are much larger than industry standards (2 mm to 3.175 mm) which reduce Hertzian force to greatly improve bearing performance.

XD15

Enduro's industry exclusive use of XD15 super stainless bearing races paired with precision ceramic balls offer improved rolling efficiency and durability.

Under load, XD15 ceramic-hybrid bottom bracket bearings get faster over time, a result unequaled by any other bearing tested. Enduro Maxhit bearings remain predictably efficient while all other brands slow down, requiring more energy (watts) to maintain the test criteria RPM rate.

XD15 is a nitrogen-infused stainless steel developed by a European aerospace consortium. An early XD15 application was Airbus's airframe control bearings that are buried deep in the airplane wings and are arduous to service. Impervious to environmental conditions and harsh chemicals, XD15 is tougher and more durable than other bearing steels because of its homogenous and fine microstructure. Over time, the extremely hard ceramic balls burnish and polish the XD15 bearing races to spin more smoothly and with less resistance. These bearings will not corrode or succumb to spalling or galling and include a lifetime warranty.

BSA Bottom Bracket Bearings for 30mm Spindles
fewer larger bearing balls roll slower and are more efficient

Maxhit

Testing confirmed Maxhit bearings provide energy saving efficiencies and will spin seemingly forever under load.

These advantages – especially apparent when bearings are subjected to axial loads – mean less energy is required to spin Maxhit bearings compared to industry standard bearings. Also, the larger 440C stainless steel bearing balls rolling over matched 440C stainless steel bearing races reduce Herztian force (material compression, deflection and fatigue) to bolster durability. Maxhit, like XD15, includes a lifetime warranty.

The initial design goal behind Maxhit bottom brackets and headsets was to improve bearing durability. Here are two of many patented features:

- Dual purposing the outer bearing race as the threaded or pressed-in bottom bracket shell interface, thus eliminating the traditional aluminum bearing retention cup.
- Doubling conventional bottom bracket bearing ball size to 5mm, while reducing the number of rolling elements.

While not included in the test protocol, engineering theory coupled with anecdotal field testing suggests bearing assemblies with larger balls provide additional functional improvements such as:

- wider tolerances that compensate for frame-to-bearing misalignment.
- a more forgiving bearing pre-load adjustment.
- rolling efficiency over relatively smaller dirt particles that sneak under the bearing seals to prevent galling, skidding, pitting and premature failure.

Bottom Bracket Bearing Fatigue & Efficiency Test

Expanded Test Observations

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In addition to the observations shared on page 4 of the Bottom Bracket Bearing Test Report, Enduro offers the following comments regarding each bearing's performance during testing.

Corrosion: While not included in this bearing fatigue and efficiency test, we wish to state that the vast majority of bicycle bearing failures are caused by environmental contamination. Water, salty sweat, grit, and sports drinks destroy bearings long before high axial loads affect performance.

In 2024, Enduro Bearings will release test results measuring the non-rotational, unloaded effects of corrosion on bicycle bearings. Bearing materials, seal design and grease quality will all play a role in the results.

BB Infinite: A somewhat surprising and disappointing result when compared to Ceramic Speed which specifies the same ceramic ball size (3.175 mm) paired with chromium steel races. The bearing became rough quite quickly, caused by what we can only guess is less than premium quality materials.

Ceramic Speed: The use of quality bearing balls and races performed quite well initially. Eventually the hardness and size (3.175 mm) of the ceramic balls proved too tough for the chromium steel races. The bearing became looser and required more energy to spin under load, although It remained fairly smooth to spin in your hand.

Chris King: The amplified test protocols proved challenging for this all-440C stainless bearing design. The relatively soft, highly corrosion resistant material paired with smaller 3.175 mm balls could not hold up to the somewhat heavy, multi-directional test loads. The seal design also seemed not particularly well suited for the test, demonstrating high drag. This bearing never really "broke-in" like the other bearings.

Enduro ABEC 3: One of three bearings tested combining more affordable high-chromium steel balls and races. In this case the balls are slightly larger (3.97 mm) than other all-chromium steel models tested, leading to slightly better performance. More on chromium steel bearings below.

Enduro Maxhit: This all-440C bearing never slowed down under load. With the largest bearing ball in the test at 4.76 mm, this performed really well under these test protocols, even though 440C stainless steel is roughly 20% softer than chromium steel.

Enduro XD15 (Radial and A/C): Combining 3.97 mm ceramic balls with XD15 nitrogen-infused stainless steel races proved to be an excellent mix of dissimilar materials resulting in a very durable and efficient bearing under these testing conditions.

Kogel: One of three bearings tested combining chromium steel races with 3.175 mm ceramic balls. This bearing performed better than BB Infinite's offering but did not hold up as well as the Ceramic Speed's bearing. We believe this is most likely related to material quality.

Race Face: Like SRAM and Enduro ABEC-3, this reasonably priced bearing uses chromium steel balls and races to provide solid performance when compared to some of the more expensive ceramic-hybrids.

SRAM: This bearing's performance was surprising in a good way. The pairing of seemingly high-quality chromium steel balls and races produced unexpected longevity under load. Definitely hard to go wrong for the price, as long as you live in a dry climate and don't wash your bike too often.

***Chromium Steel Bearings**. The drawback to these bearings (SRAM, Enduro ABEC-5 & Race Face) is that they are made of a material that quickly deteriorates in real world riding conditions, leading to potentially quick bearing failure due to corrosion rather than wear.*

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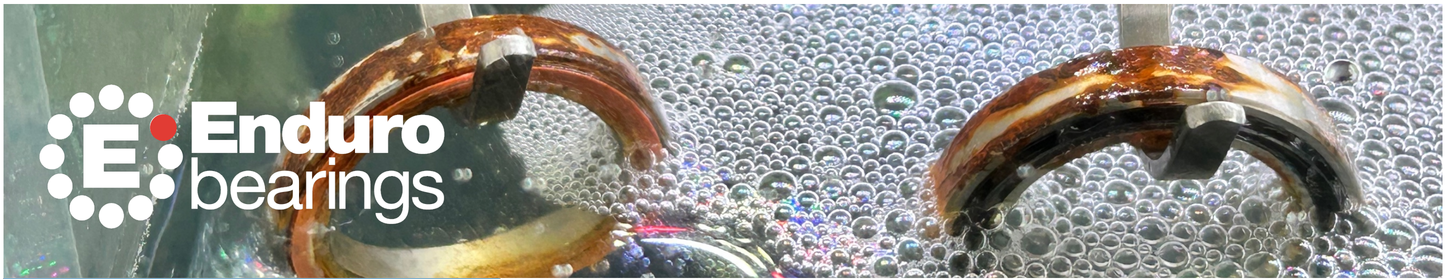

Bottom Bracket Bearing Fatigue & Efficiency Test

Accelerated Corrosion Demonstration

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The vast majority of bicycle bearing failures are caused by environmental contamination. Water, salty sweat, grit, and sports drinks destroy bearings long before high axial loads affect performance.

To visually demonstrate bearing deterioration, Enduro Bearings accelerated the effects of corrosion, we immersed the nine bearing brands included in the amplified, multi-directional load test into a salt water tank for five days.

The results of a comprehensive, peer reviewed bicycle bearing corrosion test will be published sometime in 2024.

Before sharing observations, here are key differences between Enduro's recently completed amplified, multi-directional load test and the accelerated corrosion demo and upcoming corrosion test.

Amplified, Multi-Directional Load Testing focuses on bicycle bearing design and engineering. The better the design, the more durable and efficient the bearing performs over time. Material choices, manufacturing techniques and tolerances, post machining treatments and bearing assembly practices will influence the results.

Accelerated Corrosion Testing studies environmental impacts on bearings. Bearing balls, races, seals and grease are manufactured from a variety of materials and each of these materials is available in various qualities. For example, unbeknownst to the rider, higher quality or lower quality chromium steel can be used in a 6902 hub bearing. The better the material choices, the longer it will take for the bearing to show signs of deterioration.

Bicycle bearings endure never ending abuse from inclement weather, abrasive soils, chemical contamination and neglected maintenance. When overlaying results of both the amplified load and accelerated corrosion tests, real world performance and durability assertions can be made for each bearing brand included in both tests.

Bottom Bracket Bearings included in the Accelerated Corrosion Demonstration				
Bearing Ball Material	Chromium Steel	440C Stainless Steel	Ceramic	Ceramic
Bearing Race Material	Chromium Steel	440C Stainless Steel	Chromium Steel	Nitrogen-Infused XD 15 Stainless Steel
Brand	Enduro ABEC 3	Enduro Maxhit	BB Infinite	Enduro XD15 A/C
	Race Face	Chris King A/C	Ceramic Speed	
	SRAM		Kogel	

Observations	
Chromium Steel Balls & Races	*The most affordable bearings tested, the drawback to these bearings is that they are made of a material that quickly deteriorates in real world riding conditions, leading to potentially quick bearing failure due to corrosion rather than wear. SRAM, at $41retail, is a solid value.*
440C Stainless Steel Balls & Races	*440C series stainless steel is extremely corrosion resistant but not 100% corrosion proof. Both brands included showed the slight discoloration in very small areas by the end of the 5-day accelerated corrosion demonstration. Maxhit out-performed Chris King in the amplified load test.*
Ceramic Balls & Chromium Steel Races	*Three brands tested utilize this ceramic-hybrid design. All exhibited corrosion similar to the much more affordable "all chromium" bearings. Ceramic Speed showed the least corrosion and performed the best of this group in the amplified load test. BB Infinite deteriorated the quickest.*
Ceramic Balls & XD15 Super Stainless Races	*Only one bearing design uses this 100% corrosion proof combination of ball and race: Enduro XD15. It was the highest performing bearing in both the amplified load test and the 5-day accelerated corrosion demonstration.*

Visit cycling.endurobearings.com to read or download the complete Bottom Bracket Fatigue & Efficiency Test