Chain Longevity Testing – Full Test Brief.

The chain longevity testing will follow the same test protocol as used for the Lubricant Testing project, however with a couple of little tweaks to assist with assessing chain longevity performance to a greater detail than has been achieved previously.

For each test, one half of the chain on test will be the chain being tested – the other half will be a control chain. In most cases this will be a Shimano Ultegra – however in some cases it may be a Dura Ace or 105. As over 20 tests will be done – assessing the repeatability across multiple control chains will enable us to see if anything looks amiss on any particular test that would denote that test being re-done.

Both halves of chains (chain on test and control chain) will be joined via master links at each end. In each test the control chain should wear at a similar rate to previous tests (there will always be some variance, any chain will have sections that wear at greater and slower rates, so no two chains of the same make and model will ever wear exactly the same. However the variance should be within a consistently tight grouping - and if it isn't the test will be re started with new test and control chains).

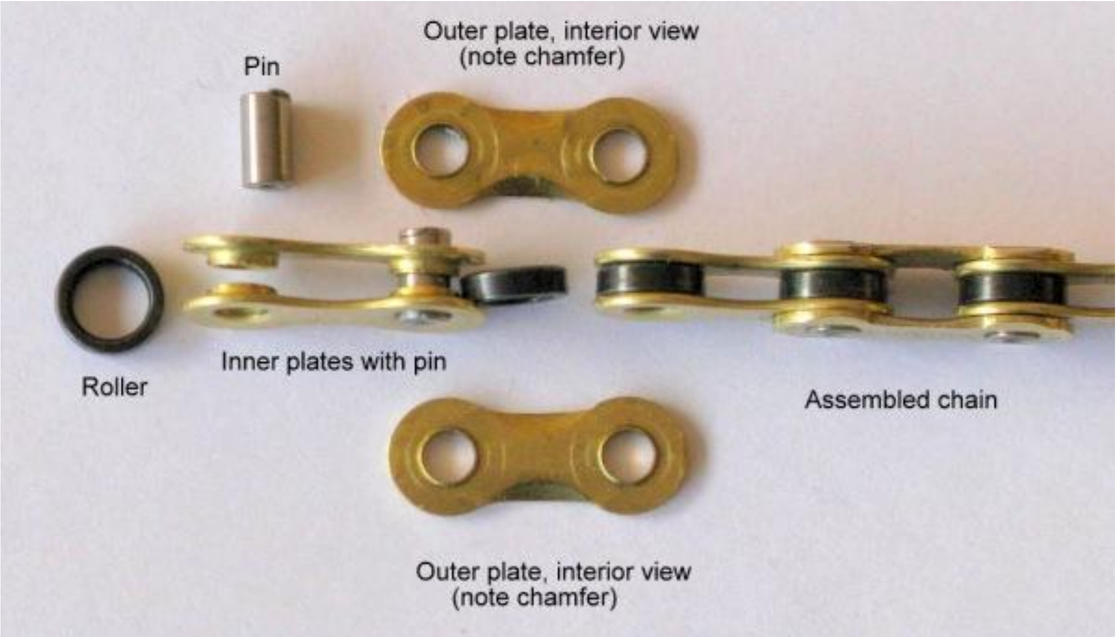
The control chain wear will be recorded along with wear rate for chain on test. For anti clutter on graph reasons it will not be displayed on test result charts however as always with ZFC testing full data sheets for all tests are available upon request.

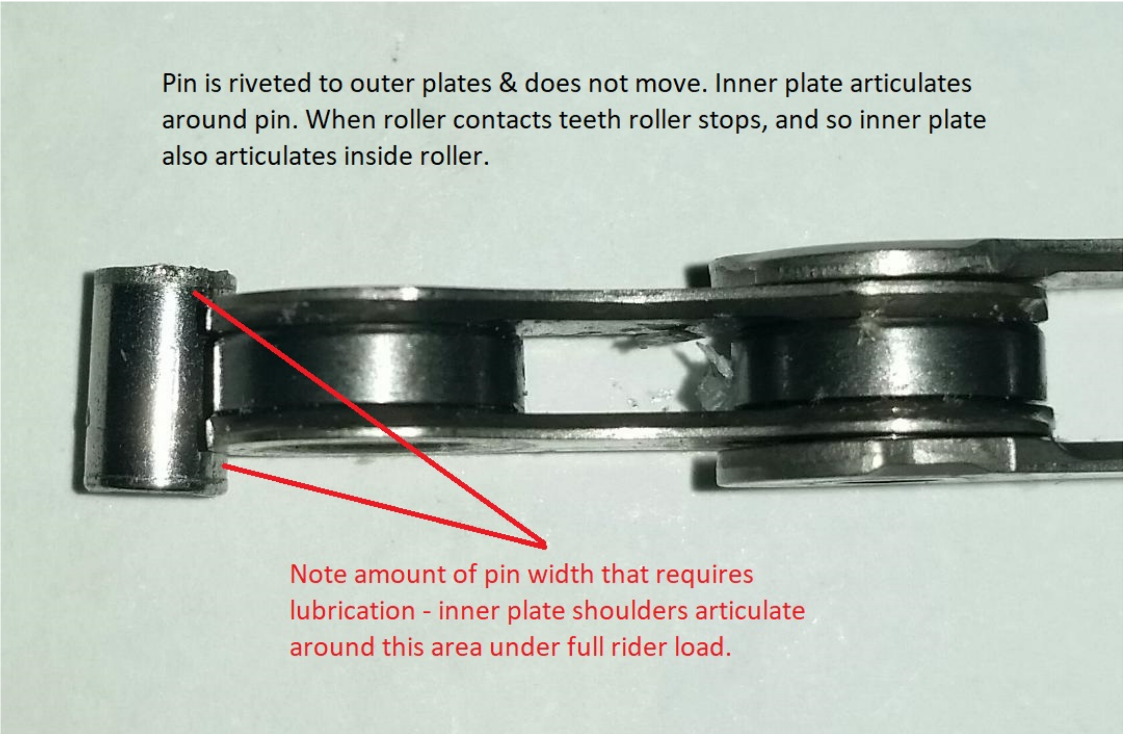
Full information on the actual testing protocol is available in full test brief document on lubricant testing page – I won't duplicate that full document here. An advantage of following the same protocol as used for lubricant testing is we will be able to see what possible variances in chain lifespan may have been obtained for a particular lubricant had higher level or lower level of chain been used. I.e if a chain obtains a notably longer lifespan during this test on the control lubricant of White Lightning Epic Ride, lubricants which delivered much better results in the lubricant testing on the control ultegra chain you should see a similar lifespan improvement with the longer lasting chain on this test with that better lubricant. Hope that made sense.

Chain wear measuring.

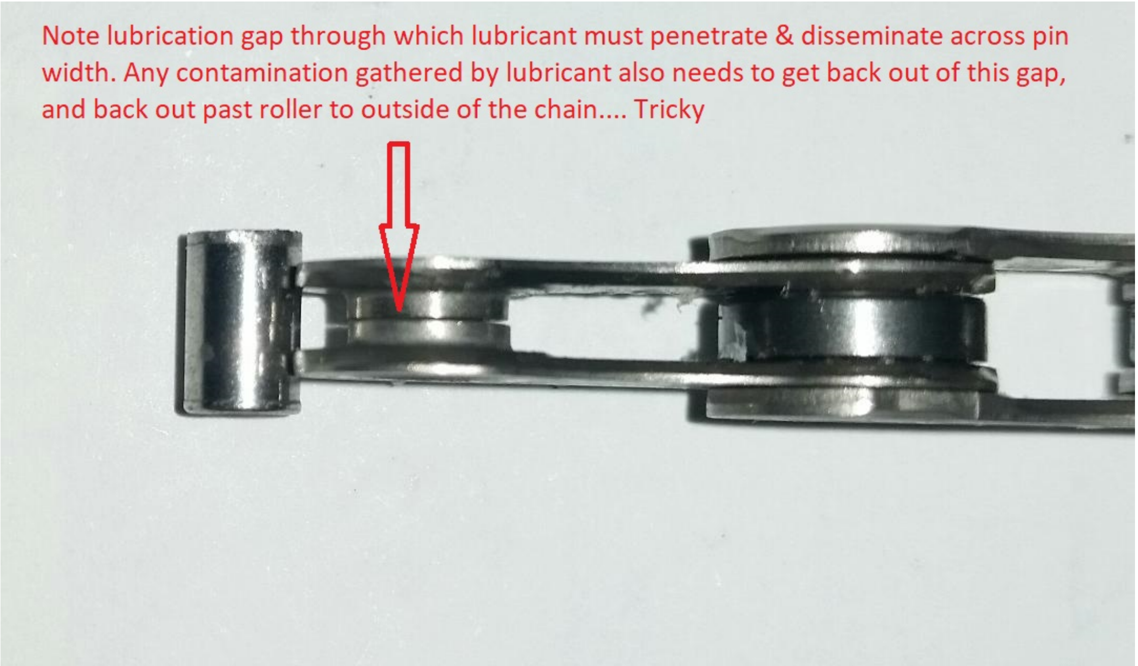
This is a fun topic indeed, and you can ask 5 experts on chains and get 5 different opinions on what is the best way to measure chain wear. I will try to explain chain wear fairly briefly so you understand why I have selected the method I have.

Firstly – whenever "chain wear" is mentioned - what is meant is "chain elongation wear". A chain is constructed via a pin which is riveted to the outer plates, the inner plates have forged "shoulders" or "bushings". A chains roller sits on top of these inner plate shoulders, and the pin runs inside these inner plate shoulders. Refer to the following images that I use to explain the lubrication gap as part of ZFC lubricant testing – the same images will give you a clear picture of chain construction and internals.


Outer plate, interior view
(note chamfer)
Pin
Roller
Inner plates with pin
Assembled chain
Outer plate, interior view
(note chamfer)


Pin is riveted to outer plates & does not move. Inner plate articulates around pin. When roller contacts teeth roller stops, and so inner plate also articulates inside roller.
Note amount of pin width that requires lubrication - inner plate shoulders articulate around this area under full rider load.

Now with the roller removed you can see a clear picture of the inner plate shoulders (or they may be referred to inner plate bushings as they serve the same function as a bushing). In a bushing chain (like a track chain) – the pin runs inside a separate metal cylinder called a bushing, and the roller then sits on top of the bushing. Derailleur chains dispense with the separate bushing and this component is forged directly into the inner plate and are known as a bushing-less chain design. This design is necessary for derailleur chain which need a high amount of lateral flexibility.



So, when a chain link comes into contact with a tooth on chain ring or cassette and articulates (bends) around it, the following occurs;

- As the pin is riveted to the outer plates, the pin does not rotate -the inner plate rotates around the pin. So there is a key wear interface between the inner bore of the inner plate shoulders and the surface of the pin. Over time the bore of the inner plate shoulders will wear to a larger diameter, and pin will wear down to a smaller diameter. As this happens, free play begins to occur between the pin and inner plate shoulders. This free play allows each link to be pulled "longer" than when both parts were original size. This wear results in "chain elongation wear".

- Also – once the roller comes into contact with chain ring or cassette teeth, the roller is held static and the inner plate shoulders articulate inside the roller. So the inner plate is doing all the physical movement of every link articulation by rotating around the pin and inside the roller. This gives us a second key wear interface between the outside of the inner plate shoulders, and this inside of the roller bore.

  Over time, this wear results in the inner plate shoulders wearing thinner from the outside in (at the same time as their bore is being worn larger so they are in fact wearing thinner from both directions), and the bore of the roller is also wearing to a larger diameter. As a chain becomes worn one can see that the rollers have a lot more free play vs when they were new – able to be moved forwards, backwards, up and down – an increasingly significant amount.

****NOTE! - The wear of the outside of inner plate shoulders and inside of roller bore is not classed as chain elongation wear, and is not generally considered as "chain wear" when chain wear is discussed – but more on this later…***

Moving on to how chain wear is measured;

There are a raft of chain wear checkers / chain wear measuring tools on the market. The majority of these tools are "drop in" checkers or similar – they are slotted against a links roller at one end and into or up against another roller at the other end of the measuring tools span – Thus measuring the length of the chain in between the span of links the tool covers. Most chain wear checkers will measure span length of 8, 10, or 12 links.

The issue many engineering types have with this style of checker is that at the two chain entry points for the tool, the tool will be measuring wear of the rollers inner bore and outside of inner plate shoulders (not classed as elongation wear), as well as the wear of inside of inner plate shoulders and pin wear (elongation wear). So at two points in the measure there is a double wear measure, but for the rest of the span of chain in between, only the elongation type wear of pin and inner bore of inner plate shoulders is being measured. This will result in a slightly higher wear measure vs if one was to accurately take a measure from centre of pin to centre of pin for the same span of chain being measured.

Measuring wear in this way isolates out the wear of rollers / outside of inner plate shoulders and so is a more accurate measure of purely chain elongation wear. Some chain wear checker tools attempt to overcome this by isolating out the wear of rollers and outside of inner plate shoulders.

Thus I have read many a forum on chain wear measuring where there are numerous passionate posts re what a waste of money chain wear checkers are when you can just grab a ruler and take a pin to pin measure across a span of chain.

However – whilst this method is theoretically a more accurate way to measure elongation wear, it can be a little problematic in practice.

Firstly – when measuring elongation wear of a chain across a span of say 10 links, we are measuring very small fractions of a mm. It is difficult indeed to manually eyeball the dead centre of pins across a span of chain to a sufficient level of accuracy. I have tried many times, and it is tricky to be extremely accurate.

Lets do some quick maths;

The pitch of our bicycle chains– distance from Pin to pin – is 12.7mm (it is the same regardless of what speed system). This means a span of 10 links the distance should be 127mm.

You take as accurate a measure as possible and measure 127.3mm – so you have measured 0.3mm elongation. 0.3mm divided by 127mm = 0.00236, x 100 = 0.23% wear. So once you have had a bit of a play, you realise that you have basically up to around 0.6mm elongation wear allowed across a span of 10 links (0.47% wear) – to remain within recommended replacement mark of 0.5%.

So each 0.1mm is equivalent to 15.6% of your wear allowance. I can tell you it is very hard to eyeball to 0.1mm accuracy. It is hard to eyeball to even ¼ of mm accuracy (0.25mm). Eagle eyed and steady handed surgeons aside, you can expect your wear measuring to be a little ballpark even when using digital calipers. You can test this by giving a chain and set of digital calipers to a bunch of mates and ask them to measure centre of pin to centre of pin across 10 links. Don't tell them a measure you are looking for – just see what you get back. The variance will usually be more than the recommended variance between new chain and recommended 0.5% wear replacement mark.

Add onto this another fun fact - chains never wear at a consistent rate across the chain. If one section measures 0.4mm, you can bet you will find another section that will be 0.5, another that is 0.3. It is not uncommon for the variances to be quite large across a chain – up to 0.4mm difference has been measured on same chains from one section to another.

So when checking your chains for wear, you really need to measure at least 3, preferably 5 to 7 separate spans of chain. Doing this to 0.1mm accuracy is not a quick, easy and reliable task. And if it is not quick and easy – the majority of the cycling public wont do it (in fact the majority don't do it – hence the majority often running their chains too long and prematurely wearing cassettes and chain rings).

And for one final piece of fun – you need to ensure sufficient and consistent tension is in the chain span being measured. Insufficient tension may not have pulled pins up against inner plate shoulders – a viscous and contaminated lubricant can easily prevent pins from being pulled all the way across into plate shoulders – giving a false low wear measure. In my lubricant testing I could sometimes increase wear measure by around 30% by putting high tension on the chain vs moderate tension during contamination phases when chain was full of gritty lubricant.

So in summary – spend the 30 bucks on a chain wear checker and don't get all faffy about the fact it measures a double wear factor at the two entry points – how do you know they haven't calibrated for that anyway when they made the tool? Just ensure you get a chain wear checker that has a 0.5 wear measure on it – not just 0.75 or 1.0. You could get away with that in the old days when cassette teeth were twice as wide and so had a lot more metal and wear resistance. 10 / 11 / 12 speed - by

0.75 you will have caused a lot of premature wear to cassette. Park tool cc3.2 is perfect, and will save you a lot of money in your cycling lifetime.

I should also quickly cover of course that some will say the most accurate is to remove the chain and measure the entire length under tension. But again this is something that probably 0.001% of the cycling population would ever get too. You need to either count how many links your chain has and do your maths, or have measured chain when new and are measuring the difference vs when it was new, and you need a place where you can measure nearly 1.4 metres of length accurately and under tension. It is still difficult to measure any more accurately than around ¼ of a mm, and it will not show you if one section of the chain is wear much more quickly than others. If one part of the chain is at 0.4% wear and another is at 0.8% wear – you will not pick this up. The 0.8% wear section will be merrily eating into your cassette etc.

A drop in chain checker can check 7 sections of chain in 30 seconds and you know if you are good or should replace. Your chain is your hardest working part, operation completely exposed, so it is also your most consumable mechanical part. Staying on top of chain wear will save you a fortune over time, so just spend the 30 bucks and get a park tool cc3.2 chain checker ☺.

That rather segue done, this should now give you the understanding of ZFC chain wear.

For the Zero Friction Cycling chain longevity testing I will be using two methods of chain wear measuring. Firstly I will be using the kmc digital chain wear checker. This measures chain wear to 0.01mm accuracy across a span of 8 links. 6 measures of 8 link spans will be taken within the 53 link span sections chains being tested (one half of chain is chain on test, and the other half is the control chain). The average of the 6 measures will be used obtain wear measure 1. If there is a wear rate differential between sections greater than 0.15mm the test may be stopped and restarted with new chains.

Wear measure 1 will include a double up of wear measure at two points each measure as it will be measuring wear of the roller bores and the outside of inner plate shoulders as well as chain elongation wear.

For wear measure 2 the chain will be removed and both the chain on test and control chain will be measured as a single span for just chain elongation wear.

Wear measure 2 should differ to wear measure 1 on the lower side.

The two different wear measure methods will enable a greater insight into a chains wear performance vs just a single wear measure method. Different chains have different levels of treatment on different parts of the chain.

Some chains have chromised or chromium carbide hardened pins, however the rollers do not. Some chains also have chromium hardening treatment on the rollers. Some chains the inner plates may be nickel plated, or titanium nitride plated, where as many have no plating's, or strangely just the outer plates for cosmetic reasons (however the outer plates play the lowest role by far in chain friction performance and longevity. They play no part in chain elongation wear, but do play a part in lateral chain wear or "chain slap" – that is not on test here).

Different level chains may also have a low friction coating applied to different parts. For instance with Shimano chains, a 105 level chain has their Siltec low friction treatment on the inner plates only. For Ultegra the chain has Siltec on inner and outer plates. For Dura Ace, Siltec is on inner and outer plates as well as the rollers.

It is very important to note that wear of inside of roller bore and outside of inner plate shoulders is still wear of the chain. Whilst it does not come under the official definition of chain wear which is meant to refer only to chain elongation wear – it is wear nonetheless. It is largely ignored or deliberately isolated out of chain wear measures as the focus is on elongation wear as the guide to replace chain - hopefully so as not to prematurely wear drive train components.

However it is time this aspect of chain wear is also considered, and to see what difference shows up with higher level chains that pay attention to the treatment of their chains rollers vs chains that do not. It is part of why you pay a premium for some higher level chains.

A high wear rate of the inside of the roller bore is likely to have a negative impact on chain friction performance and also likely to still have an impact on the wear rates of cassette and chain ring teeth. This aspect of chain wear has not been isolated and investigated by anyone as far as I am aware so I cannot give you an absolute on this – however if you have rollers flopping about all over the place it would be an optimistic stance to say this has no negative impact on chain performance. Friction Facts calculated a chain with 1.0% elongation wear will be approximately 2w higher efficiency loss vs a new chain (clean and lubed chains). Roller wear and outside of inner plate shoulder wear I am not sure if was factored into this calculation – so the losses may be even higher than this – this wear certainly is not going to help.

So the two methods of chain wear measuring ***MAY*** pick up if there is a difference in overall chain wear performance between chains that have a hardening treatment on rollers and inner plates and those that do not. For instance a chain with chromium hardened pins but no hardening of rollers should show a larger differential between wear measures 1 and 2 vs chains that also have chromium hardened rollers.

ZFC testing will test chains to 0.5mm on the KMC digital checker, same as was used for lubricant testing. True elongation wear will be lower – across 53 links 0.5% equates to 3.385mm True elongation wear will be measured and recorded as a percentage with 100% being 3.385mm – I only have the equipment accuracy to measure to approximately 0.2mm for true elongation wear at this stage.

As the same physical test protocol is used as the lubricant testing, some extra meaningful data regarding expected lifespan of chains for users will be able to be extrapolated.

Control lubricant

The control lubricant used for chain longevity testing is White Lightning Epic Ride. Friction Facts testing had this lubricant as 55th out of 55 lubricants tested re efficiency, and my testing also showed it was a poor performing lubricant resulting in a fast rate of chain wear of the control chain (ultegra chain). A poor performing lubricant with a high wear rate is desired for chain longevity testing to quickly assess the chains resistance to wear.

A little bit about hardness and wear resistance.

Measuring the hardness of metals is a rather complicated topic. For fun, there are a multitude of methods of measuring / rating metal hardness. So looking up a metal and seeing a hardness rating can be difficult to understand what that number means. It may be Rockwell hardness rating (of which there are Rockwell A, B, C or D scales), or Vickers, or Mohs, or Brinell, or Shore, and a number of others.

The most common hardness rating are Rockwell D and Vickers. Both work via using an indenter under a specific load – but how the indenter are used and subsequent calculations are very different. Rockwell method is not accurate for measuring the hardness of very small and thin parts due to the indenter's impact force which can easily cause deformation of the part being tested. For small parts that have a surface hardening / plating – the Vickers hardness test is generally regarded as the most suitable.

Mild steel / stainless steel will typically have a Vickers hardness rating of around 150 to 200. Quality hardened steel will be 200 to 400, or even 500, and the highest level tool steels / high speed steels can be up to 700.

However – the harder you make steel, the less ductile and more brittle it becomes. Steel can be made with very high "toughness" – combination of hardness and ductility – but this is very expensive requiring alloying with multiple other metals plus quite exacting heating / cooling cycles. For bicycle chains I have no doubt different manufacturers use a different level or grade of steel. Campagnolo for instance claim their chains are made of "special steel". Exactly what grade of steel is used I am unlikely to every find out from manufactures. But in summary for bicycle chains, you can expect the steel will be hardened for wear longevity but there is limit as to how hard they can make this steel without the chain becoming too brittle and snapping on the first poor shift – especially the more economical grade of steel that is used.

You may have heard of "case hardening / face hardening". This is where just the surface of the metal is heat treated in such a way that a layer of martensite forms – which is very hard. This is often used in armour plating to have a very hard surface layer to break up projectiles, but with the still ductile steel underneath to absorb impact and not shatter. Face hardening is also used extensively on cogs in gear boxes, motorcycle sprockets etc to have outstanding wear resistance but sufficient ductility not to snap under sudden forces. Unfortunately this type of treatment cannot be done on bicycle chain plates, pins and rollers – they are too thin and small to be face hardened, the entire part would be hardened and become brittle.

So this where surface treatments / platings come into play. Very hard surface treatments such as Nickel Plating, Chromium Carbide plating or Titanium Nitride plating is a method to give small parts outstanding abrasion wear resistance and have the underlying metal retaining the properties it requires for its intended purpose.

Nickel plating has a surface hardness similar to martensite at around 1000. Chromium plating – there are 3 main types of chromium plating – often a type of chromium carbide – and they range anywhere from about 1000 to up to 1800. It will be impossible to know what one of the 3 type has been used on any chromised parts on the chains on test.

Titanium Nitride plating is extremely hard and abrasion resistant with a rating typically between 1800 and 2200.

So we can see any of these plating's will increase surface hardness significantly vs chain metal which has no surface plating's. This is purely a guess – however I believe it is likely the steel used in chains will have a hardness rating likely to be anywhere in the 150 to 300 range.

Some chains may have treatments on only one part – ie the pins. it is possible that this may increase the wear rate of the non treated part. In some industrial applications there can be a "sacrificial" part which is deliberately softer that the other part it is running against as the other part may be a major component in the machine and so wear of that part is highly undesirable. It is much more cost effective to more frequently replace a more easily accessible cheaper part to keep an expensive main part lasting a very long time. However this approach does not make a lot of sense for chains. So if a manufacturer has chromium treated pins but the inner plates are not treated – the inside bore of the inner plate shoulders will be wearing at different rate to the pin. Will they wear at a faster rate if pin is chromised vs if the pin is similar hardness to inner plates? Will there still be an overall longevity benefit if only one of the two key wear interfaces has a hardening treatment?

At this stage I am unsure. In a gearbox if half the gears were surface hardened and half were not – would you have a longer lasting gearbox?

Making thing even murkier is it can be hard to pin down exactly where treatments are applied if there are treatments. It is common for instance that nickel plated and titanium nitride plated chains that this this treatment is done after construction. All the action happens inside, that is where all of the friction and wear is – wear on the outside of the chain is minimal indeed and plays a very low part in a chains friction in the drive train. So applying these super hard coatings to the outside looks great, it is great for marketing, but if it is not on the inner plate shoulders, inside of roller bores – then it will not assist with wear resistance.

And then finally we also have low friction PTFE treatments. These treatments often do make a significant difference in friction and wear until such time as this treatment is abraded off. Again, there are many types of this treatment used by many manufacturers which will last differing lengths of time, and applied to a higher or lower number of internal parts.

Lastly for fun – Wipperman recently did a great looking chain longevity test – which they won of course. Overall the test looks great – the main issue I have with it is they claim they tested all 11speed chains on the market and theirs had clearly the greatest longevity.

Unfortunately they did not test all the chains on the market at all – in fact they did not test the two that are most likely to show exceptional longevity;

- The YBN SLA – which has chromium carbide hardened pins and rollers and titanium nitride inner and outer plates and an excellent low friction treatment across all chains.
- The KMC Diamond Like Coating chain – which although the DLC is applied externally after construction – KMC claim their highest level of pin and plate hardness treatments for this chain.
- There may also be a couple of other dark horses in the list I have….

So it is a bit like claiming you are the heavy weight champion of the world, without having actually fought any heavyweight fighters just some good middle weights. Interesting.

What is also interesting is Wipperman's claim regarding the reason why their chains are so long lasting – they say it is because the plates are made of stainless steel. On the surface, this claim makes no sense. Even high quality stainless steel has a relatively low Vickers rating – normally in the 150 to 180 range, and stainless steel is also prone to galling (Galling is where sliding metal surfaces stick to each other resulting in one surface physically ripping off material from the other when they unstick, quickly leading to rougher sliding surfaces which increases the galling problem. Galling is a situation that cascades quickly leading to rather horrendous wear and part failure).

It is due to the propensity for stainless steel to suffer galling problems that your chains are not generally made of stainless steel. It is why chains tend to rust quite quickly after a wet ride if you don't take care of it by wiping dry and re-lubing. I have read forums where people are posting their frustrations why chains are made of a steel that rusts so readily, why don't they just make them of stainless steel?! - Both cost and galling is the likely answer. Wipperman may have solved the galling issue by using a specific grade of stainless steel that is alloyed with other metals to prevent this issue, and I have heard from various people who have used top wippermanns that they are indeed very long lasting – my point here is simply that claiming they are long lasting due to being "stainless steel" is not very informative or helpful. I have written to them with a bunch of questions but heard nothing back – I will of course keep trying.

But overall wippermanns testing does look great, so I am not doubting that wipperman did win their own test vs the chains they pitted themselves against – but I am looking forward to expanding the testing field and of course have testing that is independent.

For disclosure I do currently stock YBN SLA – after tens of thousands of km's of testing stuff in my own road, mtb and cx riding prior to starting zfc they did prove to be rather outstanding – however I am not beholden to any manufacturer. My entire business vision is find and stock the genuinely best in class products. If a chain / chains show up YBN – I will look to either stock those instead or as well as – simple as that. If you have followed my lubricant testing you will have seen me drop products and stock others instead based on the testing results. I am a retailer on the hunt for the best – I am not a manufacturer out to prove my own product is the best. That is the business model that funds the testing and so the independence credibility cannot be compromised. I have already had with lubricant testing the occasional feedback re isn't it funny how the products I stock all did so well in the testing! It is somewhat key to remember that the products selected are as a result of the testing. I don't think there is a retailer anywhere that puts as much effort into product selection as ZFC.

Below is the tabled results of the wipperman longeivity testing. (Note Shimano 600 is 105 level, 701 is ultegra, and 901 is Dura Ace).

24-Jan-18			
Wippermann 2017 11-speed chain wear test results.			
Rank	Chain Tested	Hours to 1% elongation	Result vs. 11sX
1	Connex 11sX	187	100%
2	Campagnolo Record	132	71%
3	Connex 11xB	125	67%
4	KMC X11SL Gold	112	60%
5	Shimano HG 901	87	47%
6	Connex 11s0	85	45%
7	FSA N1	74	40%
8	Shimano HG 701	70	37%
9	Shimano HG 600	67	36%
10	KMC X11-93	58	31%
11	SRAM XX1	57	30%
12	SRAM 1110	53	28%

Do chains with greater longevity run with lower friction?

Not necessarily. The main factors behind a chain's performance will be design, manufacturing tolerance, performance of the low friction coating etc.

However – race chains aside – in real world riding where many cyclists are getting around on fairly contaminated lubricants and on chains that have some km's under the belt which have abraded away the low friction coating – the harder surfaced, more abrasion resistant chains may offer friction advantage.

If the contamination is abrading through a softer surface faster vs a very hard surface, it is possible that more friction is involved in the action of removing the material. Get some sandpaper, press down hard and run it along a wooden surface or a metal surface – it will likely be harder to slide the sandpaper along the wooden surface.

So for the vast majority of cyclists that just add more lube and wipe chain, after 1000 or 2000km when any low friction coating is compromised there may well be a friction advantage in a premium chain that has very hard treated surfaces vs more budget faster wearing chains. Remember also that budget chains often have no low friction treatment or very limited treatment – and so will suffer from friction increases and wear from contamination much sooner.

World tour teams tend to replace their chains at around 500 to 1000km. Part of this is due to safety – the more worn a chain the more likely a breakage may occur, but a large part is also to ensure the chains low friction coating has not been abraded off.

In summary – for new chains on clean lubricants there is no empirical data or evidence that a harder wearing chain will offer a lower friction advantage, however as chains clock up the km's and lubricants become more and more contaminated – it is possible the harder wearing chains may offer a friction advantage. Personally I think the latter scenario is likely – one day I hope to be able to have tested and proven with an independent FTT machine. Again, in this area – a longer lasting chain certainly isn't going to hinder its lower friction chances.

Variance in the results

As discussed before – even within the same chain the wear rates vary from one section too another. And no two chains are the same. In fact one of the services Friction Facts used to offer was batch testing of chains so that teams knew which were "hot" chains for racing and which were best for training chains.

As such if results are particularly close – we cannot say from one test of a chain that it is definitively better or worse than the other chain. Over time with the control chains we will obtain a data grouping and therefore a +/- accuracy level for the results. However where one chain is significantly better or worse than others – then you can be assured the result is pretty clear.

So even in the wippermann tests – whilst they used a control chain for each test – we do not have the data for all those control chains, and so do not have the +/- variance for those tests. In their test and in mine – we can control the load, the run time, the lubrication, and the contamination all very precisely – but we cannot control the inherent variances in chains. So where we see in the wippermann test that sram XX1 lasted 57hours an KMC-X93 lasted 58 hours – really you could not assume that if those two chains were re-tested that the result would not be reversed – it is only a single hour of run time difference.

However – whilst we have to take into account that there will be a variable we cannot control – the chain itself – the data obtained from this testing is no doubt going to be insightful indeed re premium vs budget, and just what difference the hardening treatments and plating's do or do not make re longevity and possible performance impacts.