Zero Friction Cycling

Chain Tensile Strength Test Project Brief

Project Objectives;

>Independently tensile test chains to determine;

- As chains have become ever thinner has tensile strength decreased, remained the same, or even increased due to higher material & manufacture quality – So 12 spd vs 11spd vs 10spd vs 9spd.
- Any difference in tensile strength between super light chains with material cut out of plates & hollow pins vs chains with solid plates and solid pins
- Any difference between super cheap, budget, mid level and premium chains.
- Will any manufacturer standout – for better or worse
- Reduction in tensile strength for worn chains vs same chain new
- Relate the tensile test figure results back to the tension load that chains are subjected to in real world cycling – that part of the project subsequently covered in this document.

- If possible after main chain testing has been completed, look to see who makes most secure connecting link.

**For this project I have consulted with many very clever engineers both high up in the cycling world as well as local avid cyclist engineering buddies. Huge thanks to Neil Waterhouse of Cracked Carbon in Adelaide for fabricating the tensile test rig.

It is possible that this Tensile Test project will not have any bearing on product decisions and recommendations – it is mostly a curiosity project - But you never know, all test projects to date have thrown up some surprises, and already Cycling Australia have thrown some chains at me for testing as they will be basing some decisions for track team based on results as they have been having some issues with current chain – not chains failing but links bending after powerful sprint efforts and becoming stiff.

As a quick sneak preview however in case you do not want to read a bunch of nerdy stuff below that I put together by consulting with real engineers, I can advise that all bicycle chains, regardless of speed / width – need to be rated to 8000 newtons tensile strength (global industrial standard for bicycle chains). Taking into account some general values re chain ring size / crank size etc – let's conservatively call that around 6000watts.

Initial play around testing before getting into project proper, all chains have been exceeding this, some even over 10,000newtons. And yet interestingly some of the strongest chains tested to date I have personally seen multiple failures in real world riding at either very low or quite normal power outputs.

So what is happening? Obviously the riders aren't suddenly putting in a burst of 6000w+ to cause chain to fail. Even high power crappy shift is unlikely to replicate the very impressive tensile force required to exceed the chains rated / tested strength.

But cycling chains fail. More often than you might think. Far more than chain failure rates in industrial applications. I have seen a chain brand / model that has tested at over 12,000newtons fail in carpark whilst the rider was pedalling at about 50 watts to check seat height. Another of the strongest 11spd chains tested I have seen the same rider snap 3 in 12months in CX racing.

The short answer the project + field evidence is pointing too is that our ultra narrow cycling chains simply have very little margin for manufacture error. Where chains in industrial applications will typically have pins protruding past outer plate and be running in a straight chain line angle, our ultra narrow cycling chains (especially 11 & 12spd) have pins that are flush or even recessed into outer plate requiring perfect riveting on every pin on every link on both sides of the chain. This is a level of manufacturing precision that is not required for the vast majority of chains in industrial / machine use. So it comes down to repeatable manufacture tolerances & execution. A chain that tests at over 10,000n but 1 in every 100 produced has a single riveting defect leading to a weak link will result in many real world failures. A manufacturer who's chain tests only just above the international standard of 8000n but executes manufacturing to a higher tolerance and has 1 in 1000 chains with a weak link will experience very few real world failures as no one is really going to be pumping out 6000 watts any time soon.

Also, extremely interesting has been the initial investigations into the beefy 1/8th track chain issue for Cycling Australia. Track chains look like they could be installed on small motorcycles & Go Karts, they are huge in comparison to 11 & 12spd chains, and yet their tensile strength to failure has come out decidedly average which has been quite a shock to say the least. And, very interesting has been the failure modality with the chains stretching notably before link plate tears open around pin, whereas some of the stronger 11spd chains have had very little stretch at similar Newtons of force before a more sudden snap failure of link plate.

Initial investigations seem to point towards track chains being made of a much lower grade of steel – which is actually something predicted by a high level cycling contact who spent a good deal of time investigating chains to decide on which manufacturer to run with for their Private label chains (it is not unusual for brands to have a specific chain manufacturer make their chains for them).

This person predicted (correctly now it seems) that Track chains despite their much heavier duty looking size, will not test any stronger than quality 11 & 12spd chains. He advised you can tell this just by looking at the price. You can buy a number of good brand name track chains on ebay for around $20 to $30. There is a lot more steel in a track chain vs an 11spd chain, yet a quality 11spd chain will cost 2 to 3 times as much. If you are purchasing a lot more steel for ½ or 1/3rd the price, you are going to get cheaper steel – simple as that.

And we already know from Friction Testing by Ceramic Speed that Track chains have notably higher efficiency losses vs quality 11spd chains. They are a bushing style design (aside from the ybn sla 410 – awaiting friction testing on this chain), and most will lack the fancy low friction coating tech of quality 11spd & 12spd chains. At best - a top quality race prepped track chain will be circa 2w per 250w load slower than a similarly race prepped 11spd Dura

Ace / YBN / Campy / KMC chain (note not sram chains which whilst typically their high end chains are quite durable usually test a good bit slower vs DA / YBN / Campy / KMC).

Alas for cycling tensile strength and failure rates will not be as simple as just getting data from the test machine. Track chains have pins that protrude out of each side of the chain making a pin rivet failure extraordinarily unlikely. So a track chain with a 9400n tensile strength and an 11spd chain with a 94000n tensile strength – there is still going to be a greater likelihood of an 11spd chain fail due as it only takes one imperfect pin rivet.

However, such failures will generally occur early, so if after a few sprint efforts and link by link inspection every pin / rivet / plate looks perfect (no elongation of outer plate rivet hole at pin & no cracking near pin juncture) - odds are high that the chain will not fail at loads lower than its tested tensile strength which will be far greater than humans ability to produce.

For quite some time now all world record attempts for the hour record have been on 11spd chains vs track chains for the greater efficiency – you just do not need a massive chain with higher losses to handle 300 to 450watts – that is a doddle for an 11spd chain. If it didn't snap in pre testing and visual inspection shows now concerns, it will not snap in the event.

More and more track pursuit records and world level wins have been achieved on 11spd chains vs track chains, and now it is just starting to look like there may be some trend towards them for sprint events as well. At the power being produced it could easily be a 10 to 15w advantage in events won or lost by $1/1000^{th}$ of a second. Especially for non world level athletes pumping out 2500watts, many club track riders should be seriously considering a switch to 11spd chains vs track chains.

The significant level stretching of the track chains tested thus far prior to failure (ybn 410 the exception that had very low stretch before sudden plate snap – and at higher load rating) is the smoking gun at the moment for the bending and subsequent stiff link issues that have led Cycling Australia to commission tensile testing with ZFC.

In the mtb downhill racing world if you watch a full world cup round with qualifying and racing you will see likely around 5 chain snaps out of the start gate as they launch into their run – and yet at best most riders will be producing up to around maybe 1/3rd of the ultimate tensile strength of the chain – so the failure rate is rather extraordinary (downhill riders use 11spd chains on special 7spd cassettes that have 11spd chain spacing). Why such a failure rate when they chains they use will rate at least around 3 times the load rating they are being subjected too (and for many athletes it will be much less than this, only probably the top 1% will get near this level).

Again it simply comes down to making very thin chains without a single weak riveting point across thousands of chains far more challenging vs chains with pins that protrude outside of the outer plate. It has also not been unheard of (whilst very rare) for a “bad batch” of chains to have been produced – it can happen to any manufacturer for any type of product – things happen when humans are involved. DH racers – especially the factory sponsored riders – have a tendency to put a brand new chain on for finals – no doubt in the belief it will be safer to run a new chain vs a used chain.

The initial investigations into this test project point to this thought train is likely incorrect. A chain that has been tested with some full load sprints and inspected link by link is likely to be a safer bet than brand new untested chain.

**(There are also no shortage of world cup racers who run new chains with factory grease – in srams case – factory glue. There can be an easy 3 to 5w per 250w load by cleaning off factory grease and prepping with mspeedwax / UFO drip etc – again sometimes wins come down to tiny margins – Drive train efficiency thinking has largely not yet clicked in many mtb demographics – however slowly , oh so slowly – this is changing with some of the more up to date and progressive thinking riders and mechanics making some smarter choices..)*

So in short – in this project some anecdotal field evidence and observation is going to be just as important as the tensile test numbers – as the ultimate tensile rating of chains is well above what any human can exert. Manufacture quality and tolerance is going to be a key factor behind chain failures – not just the numbers coming out of the test rig.

Also over time I will try to get some graphs of the most notable stretch vs sudden failure’s data logs so we can see the difference between chains made of a lower grade softer metal (ie track chains) vs high quality lightweight chains failing at a similar ultimate tensile strength but in much more sudden manner vs a lot of notable stretching prior to failure. Don’t be concerned that a sudden snap fail is worse than a long stretch before fail, the sudden snap fails are occurring at loads you cannot possible produce, and if an 11 or 12spd chain is going to suddenly snap at low loads, it is going to be a pin rivet fail anyhow so it will always be exciting – you just won’t get a nice gentle stretch and more gentle fail in the real world.

Already some field / anecdotal evidence has been interesting. Remember I sell a lot of chains to a lot of powerful racers including world level. And I've also seen first hand 3 failures in 12 months for srams PCx1 which tested well over 10,000n, and a gx eagle snap in carpark and GX eagle tested over 12,000n which is huge tensile strength. Again manufacture quality is going to be key, and if you race (especially at high level events) – check your new chain link by link after initial high sprint efforts – especially DH, Track, CX, MTB which experience huge torque, and in 3 of those 4, may also experience notable chain line angles and exciting crunched gear shifts.

So we shall see what at end of much testing across many speeds and brands in conjunction with anecdotal evidence what we end up with from this fun little hobby test project.

If you are reading this and have had a history of snapping chains, please email me to let me know what model of chain, how it failed (under high load, poor shift, plate snapped or rivet failed etc).

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Right – project lead in summary done, lets nerd up and go through the forces you exert through chain and relating the tensile numbers in newtons from test machine to what you are pumping out on your bicycle in watts.

The next sections will outline the calculations, however prior to that we need to understand a few basics first.

We are converting a **<u>dynamic situation</u>** of pedalling - which we measure in watts, and winding it all the way back to **<u>a static tension figure – measured in Newtons</u>**. This has a number of mathematical components to it to work backwards. Don't worry the work back is fun and you will learn answers to cool questions such as does a longer crank give you more power vs a shorter crank etc ☺

Right, to start with, even for your power meter to give you a watts figure on your cycling computer, a lot is happening.

Power = Torque x Rotational Speed. As you apply Force through your pedals (this force input is measured in "Newtons"), this applies a "Torque" or "turning force" into your crank. Torque or turning force is measured in "Newton Meters" – it equates this force to a standard unit of what this force would be if exerted on a lever that is one meter in length. So if you are running a 175mm crank – the force on the pedals is going to be multiplied by 0.175 (there are 1000mm in one meter) to calculate how many Newton meters of turning force are being input into your crank arm.

So the torque applied is a function of both the force on the pedal and the crank length (Torque = Pedal force x Crank length). Power is a dynamic measure – it is work being done. Power is the combination of the Torque (turning force) multiplied by your cadence (or rotational speed) and this = the power you are generating in Watts.

In short half the force exerted on a pedal but at double the cadence will = the same power as double the force exerted on a pedal at half the cadence.

But arriving at watt's figure from your power meter to your cycling computer is not so simple. The amount of force you exert upon your pedal is changing rapidly during the pedal stroke across a full revolution of the crank. Every full pedal rotation sees highly variable forces being exerted on the pedal and therefore into the crank as the pedals move through different points in the rotation. The maximum force generated is typically when the pedals are in the 2 o'clock to 3 o'clock position where your legs major muscles are able to exert force easily, while the lowest force is typically generated when one's pedals are at the 12 o'clock and 6 o'clock position.

As such, your power meter is sampling the force being exerted hundreds of times per second throughout a crank revolution, as well as the rotational speed. The final nice neat watts figure you see on your cycling computer is the average of all that data calculated and averaged for each complete crank rotation. Depending on your power meter and cycling computer, it may have taken as many as 512 measurements per second of force / rotational speed (512hz sample rate), all of which is then calculated out to attain the average force x speed for that crank revolution to deliver you a nice and neat wattage number.

Next – we need to remember that for a given power figure there were higher and lower forces applied throughout the crank revolution. This is very important as we can then understand that the peak force and therefore tension applied to the chain is going to be greater than the average force calculated for a crank revolution. Back calculating a tension force in Newtons from X watts will not be an accurate representation of the peak tension the chain experience during high power generation phases of the crank revolution.

If we just calculated back chain tension from the average power during the rotation then we would obviously underestimate the maximum tension in newtons exerted on the chain – but by how much? We get to that bit covering some pedalling dynamics after this next little section to confirm understanding of the forces and measures.

Okay – so for a given power, to transfer this from the chain ring to the cassette, the chain will be under tension force, and the SI unit for tension force is a Newton. A newton of force is a bit over 100 grams – 1 newton of force is about the same force as decent sized apple.

Torque – or turning force – is measured in Newton Meters. This is one newton of force (or one big apple) sitting on the end of a lever that is 1 meter long – which is a pretty big lever.

So if you had a crow bar that was one meter long, held it horizontally at one end and sat a nice big apple on the end of it, that is going to be basically one newton meter of turning force applied.

Newton meters are often converted into Kilogram Force (Kgf) as it is easier to imagine X kg of weight vs Newtons or an orchid's worth of apples. It is not an exact conversion but very roughly 10 Newton meters (or 10 apples on the end of a 1 meter crowbar) is equivalent to 1 kilogram force (kgf) – or sticking a 1kg weight on the end of horizontal 1 meter long crowbar.

A watt is a dynamic measure. 10 watts of energy roughly converts to the equivalent of vertically lifting 1 kilogram over a distance of 1 meter in a time of 1 second. So 100 watts will lift approximately 10 kilograms a distance of 1 meter in 1 second, 1000 watts will be able to lift a bit over 100 kilograms 1 meter in 1 second and so on. 1000w is an impressive amount of power – which is why a rider exerting 1000w can accelerate across the road rather rapidly indeed until wind resistance starts playing havoc.

Right – now that we have our basic force and power measure units down pat, we need to bring the watts figure you see on your cycling computer and your possibly new found understanding of turning force (torque) in Newton meters or Kgf (Kilogram force) all the way back to a static chain tension figure in Newtons to compare to the results we see from my tensile strength test machine. To do this and take a dynamic measure and turn it into a static measure, first we have to pick some assumptive values to calculate backwards.

We need;

- A power output
- Crank length.
- Chain ring size (chain tension in Newtons = Crank Torque divided by chain ring radius, so bigger chain rings for same power on same crank length = lower tension, smaller chain rings for same power and same crank length = higher tension).
- Cadence so that we can calculate rotational speed for that crank length.

Calculating the tension back from the above will only work for the given values chosen. If you keep the power the same but change the chain ring size, the tension will change. Smaller rings will increase chain tension (and by way of doing so – chain efficiency losses as links are articulation under higher tension / load, as well as requiring a greater amount of link articulation). Larger chain rings will decrease chain tension for a given crank length and power.

Changing crank length will change chain tension, longer crank = more torque & therefore tension, shorter crank = less torque and tension.

Decrease cadence but aim to produce the same power you need to increase force into pedals and therefore chain tension will increase. Aim to increase cadence for the same power number the force required to be input into pedals decreases and so does chain tension.

So for a quick segue again - For those who have debated with their friends at the coffee shop whether or not longer cranks give you more power, the answer is it depends. Longer cranks give you more turning force or Torque. A longer crank will help you get up a 30% pinch in a mtb event where even in your lowest gear you may only manage 30 cadence on some tough pinches. But for more normal cadences, a longer crank at say 85 cadence = higher pedal rotation speed as the pedal has to go around a bigger circle in the same time if the crank length is longer. This of course requires a higher foot speed, which requires higher leg movement speed.

For any given rider there are neuromuscular and efficiency limits above which a given pedal speed will be pain indeed to sustain. If not we would all be riding around at 200 cadence and keep the force required to be exerted on the pedals extremely low for any given power output. What is a comfortable cadence for any given rider is highly variable. Professional riders – especially from track back grounds – tend to have beautifully smooth pedal strokes even at cadences in the 130 to 150 range. A recreational rider with a far less efficient pedal stroke will be bouncing up and down on the saddle at those cadences, or in some cases not even be able to attain them – and if they can – the timing of the firing of the muscle fibres will be all over the place leading to very inefficient riding.

Conversely riding all the time with a very low cadence requires high muscular force generation for every pedal stroke typically leading to earlier muscle fatigue. Professional road cyclists will typically have a cadence of around 100 all day long as they have developed a beautiful pedalling dynamic from many years of practice doing so. Recreational riders are typically in the 70 to 90 average range.

Anyhoo – in short, there are limits to pedalling speed, but the variation between riders and what is comfortable will be high. However, maintaining a higher cadence is easier on a shorter crank length vs a longer crank length as the pedal needs to travel faster and faster to complete a revolution as the crank arm gets longer.

Track riders in a lot of events often use shorter cranks – typically around 165mm. Track events often have the rider doing 130 cadence+ easily after accelerating up to race speed, and from a neuromuscular efficiency perspective this is much more easily attained on shorter cranks. Cross country mtb riders rarely do 130 cadence up steep climbs, and the tough pinches especially often see cadences drop to very low numbers, sometimes the rider is using huge amount of force or torque just to turn the pedals over, so a longer lever for more torque for the same pedal force is generally favoured. (*this is again offset for many enduro / DH riders who tip back to shorter cranks for a lower likelihood of pedal strikes, but as they are only timed going DH, the lower torque is not really an issue).

So in summary – there is your answer to do longer cranks give you more power – the overall answer is no, because of limitations re feet & leg speed from the bigger circles longer cranks make you complete for a given cadence, but **they do** give you **more torque**, so it's a horses for courses choice. In general for road riding, you need the crank length that suits your leg and biomechanics vastly more than you need a longer lever for more torque – providing you have the gearing ratio's to maintain a good cadence on the level of climbing you do. If your gearing has your cadence drop too much when in lowest gear, you need to increase force generated into pedals to maintain same power which will lead to earlier muscle fatigue.

In the majority of cases riders benefit from erring on the side of a shorter crank – ie a 170 vs 175, for a much more efficient pedalling motion and ease of maintaining a higher cadence – but this can be a complex area best solved by a very good bike fit with a suitably qualified person – something that most definitely should be done prior to investing in an expensive power meter crank to ensure you get the right crank length.

Segue over, back to converting dynamic watts to static tension in chain;

To start with, let us use 400w power output, at 100 cadence, with a 53t chainring and 175mm crank length.

Don’t worry if the next bit loses you, it will all come back to normal person speak soon ☺

Putting out 400 Watts at 100 RPM, they are pedalling at a Rotation Speed of (100 RPM) x (0.1047 rad/sec/RPM) = 10.47 rad/sec, so their Torque = (400 Watts) / (10.47 rad/sec) = 38.20 Nm applied to the cranks.

Crank Torque = Pedal Force x Crank Length

Pedal Force = Crank Torque / Crank Length

Pedal force = 38.2 Nm / 0.175 = 218.3 N.

To convert to a force at the circumference of the chain ring, you just need to account for the radius of the chain ring. The radius of a 53 chain ring is 107.5mm.

Therefore;

Chain Force = Crank Torque / Chain ring radius

=38.2. Nm / 0.107505m

=355 Newtons

So there is magic figure number one that we need - 355 Newtons of tension. This is the average force experienced during the crank’s rotation at 400W, 100rpm, with a 53t chain ring.

But we know from previous paragraphs that the average force during a revolution represented by that 400w figure on your cycling computer does not represent the peak force that will be exerted through the chain as each revolution has dead spots and peak power generation phases within each revolution. Having a look at some data from cycling dynamics it is relatively safe to assume that for many cyclists the force during peak phase will easily be around 150% of the average force of a crank rotation. Therefore - for relative assumptive purposes, we can call our 400watts that equals 355 Newtons of tension force average and increase that tension by figure BY 150% to equal 533Newtons of tension from peak force that would have been exerted through the chain to generate that 400w power.

Below is a diagram showing what a beautiful pedal stroke would look like if you have pedalling dynamics being measured by your power meter and a most magnificent pedal stroke. In the below example, peak torque (and therefore chain tension) is just over 150% of average torque for 1 crank revolution;

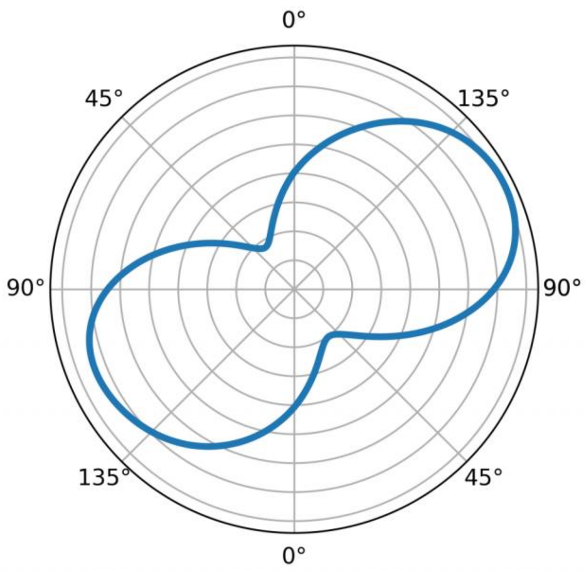
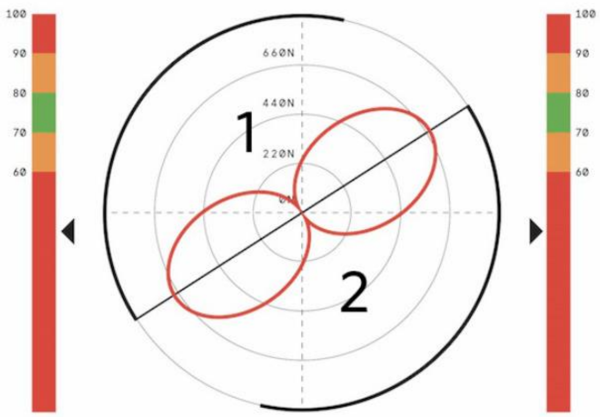


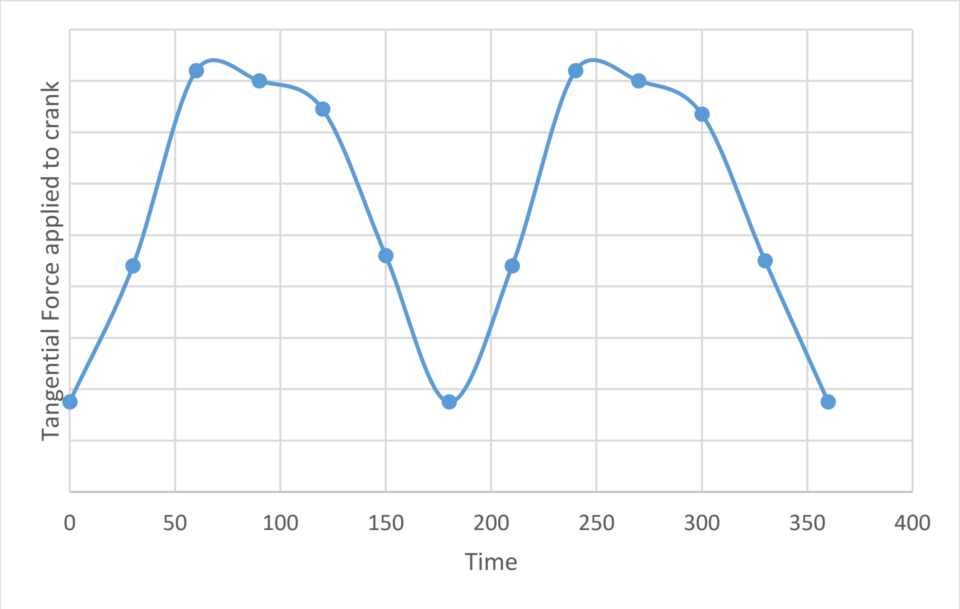
**Diagram above and below sourced from team zwatt – great source of info re cycling dynamics - https://teamzwatt.com/training/best-way-to-visualize-cycling-dynamics/.*

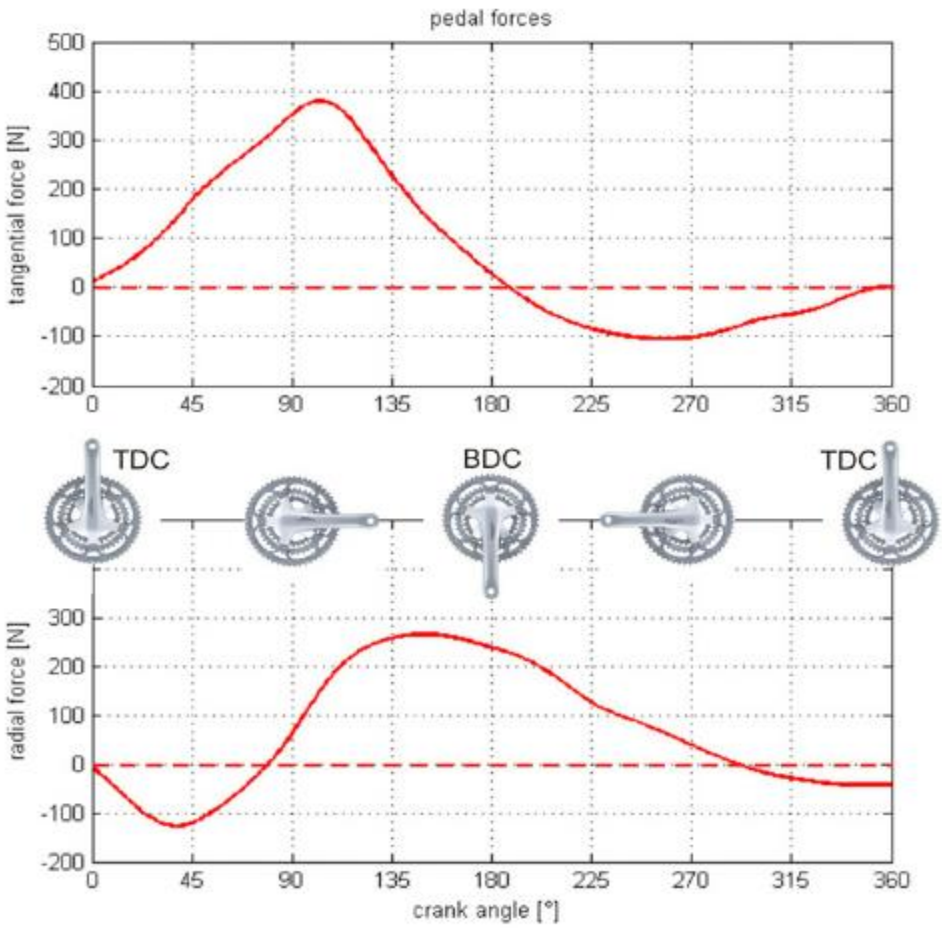
Now what if the cycling dynamics is altered due to say stand up pedalling? , or a less efficient pedal stroke (mashing the pedals, pedalling in squares etc), or possibly what may be happening during a stand up sprint? The pedalling dynamics can change dramatically and may look something more like the diagram below, in this example peak torque (and therefore chain tension) is just over 200% of the average torque for 1 crank revolution;



https://magazine.bikesoup.com/cycling-efficiently-perfecting-pedal-stroke-power
**Their website certificate has expired so may show as unsafe in browser, a further resource of great info re above can also be found here:*

And here are a few more fun charts that form the basis behind the 150% peak vs average torque (and therefore tension) calculation sourced by one of my handy cycling engineer buddies…





I don’t have same charts for stand up sprint pedalling situation, but for assumptive torque & tension purposes it is not a stretch at all to call peak tension at around 200% of the average tension for the crank revolution (as per pedalling dynamics diagram previously with two red ovals depicting torque through 1 crank revolution).

Also, pedal efficiency itself for the same athlete is likely to be quite fluid – it will likely be a completely different profile during a stand up sprint vs pedalling at tempo up a 4% climb sucked along in the draft of a peleton. Pedalling dynamics are almost certainly going to vary to the positive with a good tailwind, and to the negative with a solid headwind.

However, using 150% for peak vs average is a very accurate assumption for a lot of pedalling situations – especially in road cycling, and 200% peak vs average would be a very safe assumption for pedalling situations such as stand up sprint and a lot of low cadence mtb / CX situations (plus track event starts before track rider gets up to their beautifully smooth cadence).

Working from the above, we can now put together some tables that convert watts you see on your computer to Newtons of force being exerted into chain;

Watts to Peak Newtons & Kgf conversion Table 1 - High pedal stroke efficiency - Peak tension 150% of average tension for 1 revolution			
Watts (53t ring, 175mm crank, 100 cadence)	Newtons of Force - Chain	Kilogram Force (Kgf) - Chain	Kilogram Force (Kgf) - Pedals
400	533	54	22
600	799	82	33
800	1,066	109	45
1,000	1,332	136	56
1,200	1,599	163	67
1,400	1,865	190	78
1,600	2,132	217	89
1,800	2,398	245	100
2,000	2,665	272	111
2,200	2,931	299	122
2,400	3,198	326	134
2,600	3,464	353	145
2,800	3,731	380	156
3,000	3,997	408	167
Industrial Standard for Chain Tensile Strength = 8000N			
*Based on peak being 150% of average			

So we can see that even when pumping out a solid 400w, we are really only exerting around 533N of tension on a chain that should be rated as a minimum to 8000N which gives us a safety factor of 15. Sit down power it would take quite a specimen to achieve 1000w, which is going to be around 1332N, still giving us a safety factor of 6.

Basically with a good pedal efficiency, a cyclist would need to be approaching 6000w mark to be hitting a chains minimum rated tensile strength.

You can see a line highlighted in red, this is the point where to generate that power how many kilograms of force would be needed on the pedal. From some research it is generally accepted that it is extremely difficult for most to exert greater force than their bodyweight on the pedals, even during stand up sprints. So that 100kgf of force on the pedals is a very very safe upper physiological limit likely to be encountered in real world, and honestly in general at a 100 cadence 99% of cyclists are not going to attain anywhere near that number.

There are conditions that will change the above figures somewhat though;

Let us look at what may be happening during a stand up sprint, where pedalling efficiency is likely to change dramatically, and move from that beautiful peanut shape example that is the goal of those using cycling dynamics, more towards the two red ovals where peak torque & tension is going to be at least around 200% of the average tension for a crank revolution. This would give us a table that looks like the below;

Watts to Peak Newtons & Kgf conversion Table 2 - Poor pedal stroke efficiency - ie stand up sprint - Peak Tension 200% of average for 1 revolution			
Watts (53t ring, 175mm crank, 100 cadence)	**Newtons of Force - Chain**	**Kilogram Force (Kgf) - Chain**	**Kilogram Force (Kgf) - Pedals**
400	711	72	54
600	1,066	109	82
800	1,421	145	109
1,000	1,777	181	136
1,200	2,132	217	163
1,400	2,487	254	190
1,600	2,842	290	218
1,800	3,198	326	245
2,000	3,553	362	272
2,200	3,908	399	299
2,400	4,264	435	326
2,600	4,619	471	353
2,800	4,974	507	381
3,000	5,330	543	408
Industrial Standard for Chain Tensile Strength = 8000N			

Now we can see that a top amateur sprinter at around 1400w will be approaching 1/3rd of the chains max tensile rating – again remembering that rating is for a straight chain line only. And a huge powerhouse like Marcel Kittel at his best doing 1800 to 2000w MAY be putting chain under a strain of around 40% of what it should be rated to handle in a straight chain line, and a mountain of a track sprinter approaching 2500w for a few seconds COULD be approaching 50% of the chains tensile limit. I say MAY and COULD as remember the above are from calculations based on assumptive figures from pedalling dynamics and peak tensions for a very small fraction of second during pedal stroke and….. we do start to run into an issue where the converted KFG force is approaching double bodyweight or more for the athlete which is simply unlikely to ably to be generated except for maybe 0.01% of top sprinters – so attaining such high levels of chain tension are extremely difficult.

Where we look at extreme situations such as a track sprinter out of the blocks heaving into pedals we can run some numbers of X watts at very low cadences which show extremely high newtons force exceeding 8000n, however it is important to remember that everyone is limited by just how much pedalling force can be exerted. Even for track starts this is generally limited to around possibly 1.5 to 2x body weight. It is not believed one could realistically exceed this although open data on this front is thin to say the least, however I have had some chats with smartest people I know at the top of the cycling world and really 2x bodyweight force is really going to be a stretch. One head a major cycling company who just happens to be researching chains at the moment (handy timing), advised that they are working with 3x body weight max pedal force as a safety factor but that it is unlikely even a 100kg world class powerhouse rider would ever be able to exert 300kg of pedal force. That is essentially doing a 300kg one legged squat, as well as needing your arm pulling against handlebar to counteract a solid % of this force. It is simply unlikely to be possible. Even 2x body weight of pedalling force would only be able to be – maybe - attained by a very few of the most powerful track sprinters in the world.

Suffice to say, it is likely for most that even a very thin 11spd or 12spd chain is going to be perfectly capable of handling track sprint loads, however for very powerful sprinters they may be approaching a safety factor of 3 (ie using up to 1/3rd of the chains max tensile strength rating). As a comparison in industry, safety factors of around 8 are more typical to help guard against failure which may cause expensive subsequent damage – think of say the timing chain in your car engine where failure will lead to the destruction of your engine – and it is also why in industry chains are typically replaced very early vs the chains outright lifespan.

So, without doubt for the upper end of cycling applications, we are running lower safety factors than what industrial / machine applications would run, and that is before we have looked at aspects such as chain line angle, crappy shifting, wear, and most crucially – the fact that our ultra narrow derailleur chains do not have pins protruding outside of the outer plate but require being riveted flush to ensure fit the narrow cog spacing. The pin riveting of ultra narrow chains is likely going to be the real world weak point, and it is certainly possibly that some manufacturers have a better riveting process as well as more consistent manufacture execution than others.

If all manufacturers executed this crucial aspect to exactly the same level I sure would be surprised.

The previous tables were for road based cycling, with 53t rings and 100 cadence. If the same power was being produced, but the cadence halved, then the tensions in the above tables would double (*assuming no change to pedalling dynamics and the rider was capable of doubling for force at that cadence). If the chain ring size was much smaller, the tension would also increase relative to the reduction in radius, so all of sudden a situation like a Mountain bike rider smashing up a 25% ramp in a 32t chainring at 50 cadence – and in this case I am splitting the difference and using a 175% factor for peak vs avg power phase generation – we can see how quite commonly much higher tensions can be placed upon chain in MTB / CX riding.

Below on this scenario is the table below;

Watts to Peak Newtons & Kgf conversion Table 3 - Mtb - Steep ramp, 32t ring, 50 cadence - Peak tension 175% peak vs Avg due to impacted pedalling dynamics			
Watts (32t ring, 175mm crank, 50 cadence)	Newtons of Force - Chain	Kilogram Force (Kgf) - Chain	Kilogram Force (Kgf) - Pedals
400	955	97	45
600	1,432	146	67
800	1,910	195	89
1,000	2,387	243	111
1,200	2,865	292	134
1,400	3,342	341	156
1,600	3,820	390	178
1,800	4,297	438	200
2,000	4,775	487	223
2,200	5,252	536	245
2,400	5,730	584	267
2,600	6,207	633	290
2,800	6,685	682	312
3,000	7,162	730	334
Industrial Standard for Chain Tensile Strength = 8000N			

It is certainly not uncommon for elite mtb riders to pump out circa 800w at low cadence to smash over a steep ramp, especially on early short ramps during an XC race. This will have a tension around 1900 Newtons, and likely on a notable chain line angle – for which we as yet just do not know how much this reduces the tensile strength rating. There will still be that outright safety factor of about 3 to 4 in general even for elite riders – but again this is half general machine / industrial safety factor, and sans the knowledge of how much chain line angles and crunched shifts further reduce this safety factor, it is not that surprising that we see vastly more chain fails across the board in mtb and cx riders vs road, even at recreational level. There will not be straight 8000/1900 = 4.2 safety margin.

Again you can see red line which would denote the likely maximum pedal kgf likely to be possibly exerted and therefore the likely max possible chain tension which in this case at 1400 watts is approaching a safety factor of around 2.5, even in a straight chain line.

Safety buffer.

As I complete testing across many many chains from super cheap to premium, solid plates to lightweight with heavily cut out plates, and 12spd down to 9spd, and also track chains - it will be very interesting to see what the numbers come out. It is quite possible that all chains across all speeds test above International standard of 8000N, and some above German standard of 9200 Newtons. It is possible that pretty much all 9spd to 12spd chains and even most track chains come out between say 8000 and 10,000 Newtons.

At this stage I wouldn't get too caught up in a chain that tests at 8,500N and one that tests at over 10,000N for derailleur chains as repeatable manufacture quality – especially re pin riveting - is going to be far more important than a tensile number that we physically cannot produce, not even by half. Again to date I have already seen multiple failures in CX for one of the strongest chains tested to date, and no failures amongst other brands with lower tensile test numbers.

It is clear in cycling with our tiny chains there are times when the safety factor we are running is much lower than is the standard for industry applications – however, for most of road cycling & especially the vast majority of riders & riding situations we will be well within that 8x+ safety factor. Other situations and applications it is possible this may be reduced down to maybe as low as around 2.5.

I will be working with an engineer over time to see if we can introduce a method to test chain line angles, first attempt unfortunately the couplings were failing prior to the chain, and at values over 8000n. The angles simulated were typical big ring big cog chain line angle, so an initial foray would seem to show that derailleur chains are not unduly impacted by chain line angles they are designed to run, again assuming all pin rivets are perfect.

Fatigue / Wear;

Some other research reading revealed chains, being made of steel, do of course have a fatigue limit strength. Therefore over time, there are a finite number of stress cycles a chain link can experience before failure. The greater the % of the chains ultimate tensile strength per stress cycle the links are subjected to, the lower the number of cycles that can be experience before failure. The lower the %, the greater number of cycles. This particular article was looking at industrial application, however the same would apply for cycling.

For industrial application, they recommended a “fatigue strength” use limit of around 15 to 20% of the ultimate tensile strength of the chain. This will ensure chain reaches recommended wear replacement mark prior to getting near its fatigue limit, and as such recommended a safety factor of 5 to 7 (again think of car engines camshaft chain etc).

We can see in cycling that decently powerful recreational racers will be attaining tensile forces that can approach a safety factor of 5, or even 4, and elite track sprinters / mtb riders possibly 2.5.

Depending on the type of riding you do and how powerful you are – running worn chains for important races would not be a great idea, same as running a new untested chain is not a great idea.

Overall though for cycling application we have a minor paradox. We can see there are times where it is possible the tensile forces may be much closer to the ultimate tensile strength than would ever be used in industry, however on other side of the equation the majority of our riding for most cyclists is going to be between 150w to 250w. 200w is going to be around 300n max depending on pedalling dynamics, which even for the minimum 8000n is a safety factor of around 27 – which is a pretty solid safety factor.

So we can see that in cycling despite our very thin chains, even with chain line angles which may impact ultimate tensile strength by an as yet unknown amount – the majority of the time we are going to be cycling around with a huge safety factor, however for some short bursts and sprints there may be times when we exceed normal industry safety factors – however assuming chain manufactured sans any flaws - there should still be plenty of real world buffer.

In summary for the moment, we can say that when a bicycle chain fails it is not because the forces exceeded the chains rated strength, it will be due to a manufacturer error, worn chain, poor shift + possibly those factors in conjunction with chain line angle which will place more stress on the pin riveting.

A light to medium weight rider who doesn't do sprint efforts but just trains within a fairly normal power range may never expose a weaker link in a chain, but a more powerful rider who trains high intensity intervals and sprints may.

Chains break – this is a fact, and based on the tensile strength ratings they should still be at worst 2.5 times stronger than the force any cyclist can possibly produce – so still in theory they shouldn't be breaking, but they are, and even though I do not have data to back this up, I am exceeding confident that bicycle chains are failing at a far greater % vs chains used in industrial / machine applications which adhere to calculated safety factors re load vs ultimate tensile strength and strictly pre-determined wear / stress cycle replacement intervals.

So I wouldn't say it is common per see for cycling, but it is certainly not uncommon either.

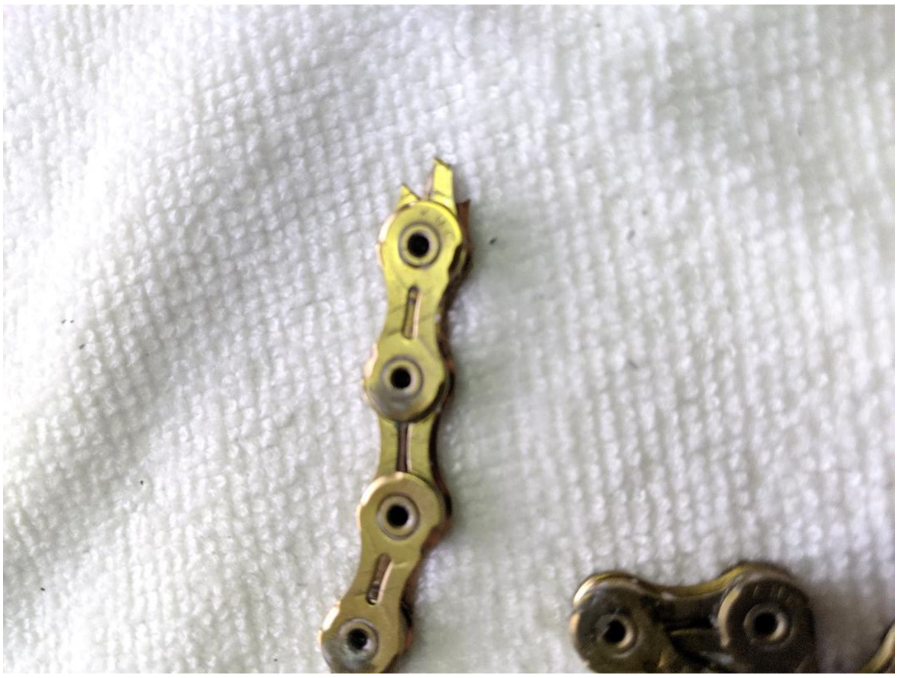
Hence why this little nerdy side project has kicked off, and already ZFC is hot on the case in assisting Cycling Australia re some possible changes in what chains they may use for events at Olympic / world level. Keep an eye on the tensile test page for test updates, and as progress further into project will either update this document or commence a project test wrap summary document.

Some initial test machine vs real world failure pics;

Pic below is what is occurring with vast majority of initial test failures as bedding in machine and software operation. We can see that despite being a straight pull, the outer plates are bursting off rivets due to elongation of hole in outer plate for the pin. So it is failing at the rivets, it a straight pull, but mostly due to elongation of outer plate hole making it impossible for pin rivets to retain plate. The tensile force required to cause this has been very high (around 9000n). This places high confidence in the strength of derailleur chain riveting for running chain line angles without a notable compromise in ultimate tensile strength.

Real world failure 1 – See elongation of outer plate rivet holes on pins – this is area is what should be closely inspected on race chains after sprint efforts before CX / MTB / Track sprint events.

Failure example 2 – snap at plate vs rivet; KMC chain. Visual inspection of chains should also look for any hair line cracks in inner & outer plates at around this point in link, this has been most common area of link snap failure should chain fail via this modality vs outer plate coming off rivet.



Izumi Super toughness 1/8th track chain – after significant stretching inner plate links tore open over pin. This was repeated each test and same failure modality for Izumi Standard.

Cog Failure on test machine coupling at around 8000n with 5dg chain line angle mimicking big ring / big cog chain line. Initial investigations hint that for derailleur chains with no manufacturer errors any reduction in outright tensile strength for chain line angle will not bring chain below international standard of 8000newtons which is still far more than what can be physically produced by humans. As such, tensile strength of chain on chain line angles should not be of concern however such conditions will be much more likely to expose any slight manufacture error, it just takes one pin rivet to be weak – Chains do snap more often on chain line angles vs straight, especially in high torque / poor shift situations, and worn chains will again be more prone to failure.