Necessity and Invention:

Getting Durability Right and Winning

William V. Mars, Ph.D., P.E.

2022 Harold Herzlich Award Address

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Endurica

Get Durability Right®

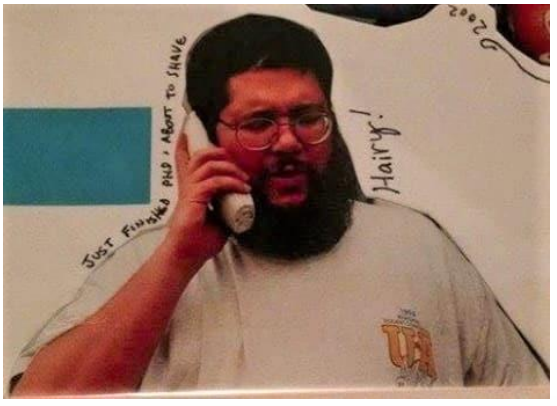
Good morning. It's a huge pleasure to receive this award. I'd like to thank the committee, my team at Endurica, and everyone who has been a supporter over the years. I am grateful for the chance to spotlight what we are doing at Endurica and why. If you haven't heard of us, the place to start is with our tagline: get durability right. We provide the tools that tire companies need to get durability right.

I am an Akron man. I was born just a mile or two north of here. I grew up in the area. In high school, my sport was the science fair. I loved airplanes and rockets. I went to the State Science fair with a project on aerodynamics. I built a windtunnel and I wrote code to analyze lift and drag. I had dreams of going into aerospace, which is why I chose Mechanical Engineering when I went to U Akron.

When I made that choice, if you can believe it, I did not understand that Rubber was where all the engineering jobs were in Akron! I also did not understand that the reduction in defense spending at the end of the cold war would make it difficult to enter aerospace. But these two circumstances set the stage for much of my life since. And this is why I am titling my talk "Necessity and Invention". We'll get to the sub title in a bit…

First Contact with FEA / Simulation

Sam Clark John Luchini



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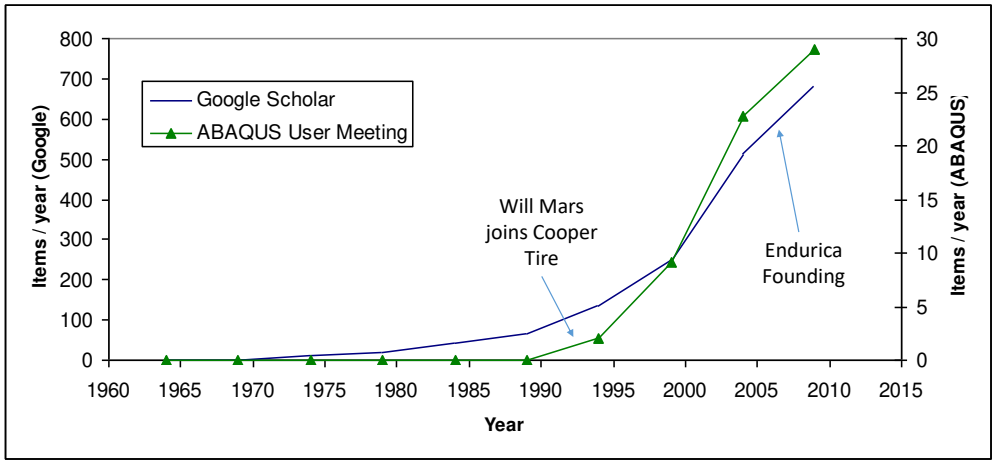
After my undergrad, I was hired into a research group by John Luchini at Cooper Tire. John was responsible for Cooper's efforts to establish a computer simulation capability for tire analysis.

My first large project was to adapt the structural code that Cooper had already written to solve for stress and strain, and to extend it so that it could also solve for temperature. Everything was FORTRAN. It took me a few years complete.

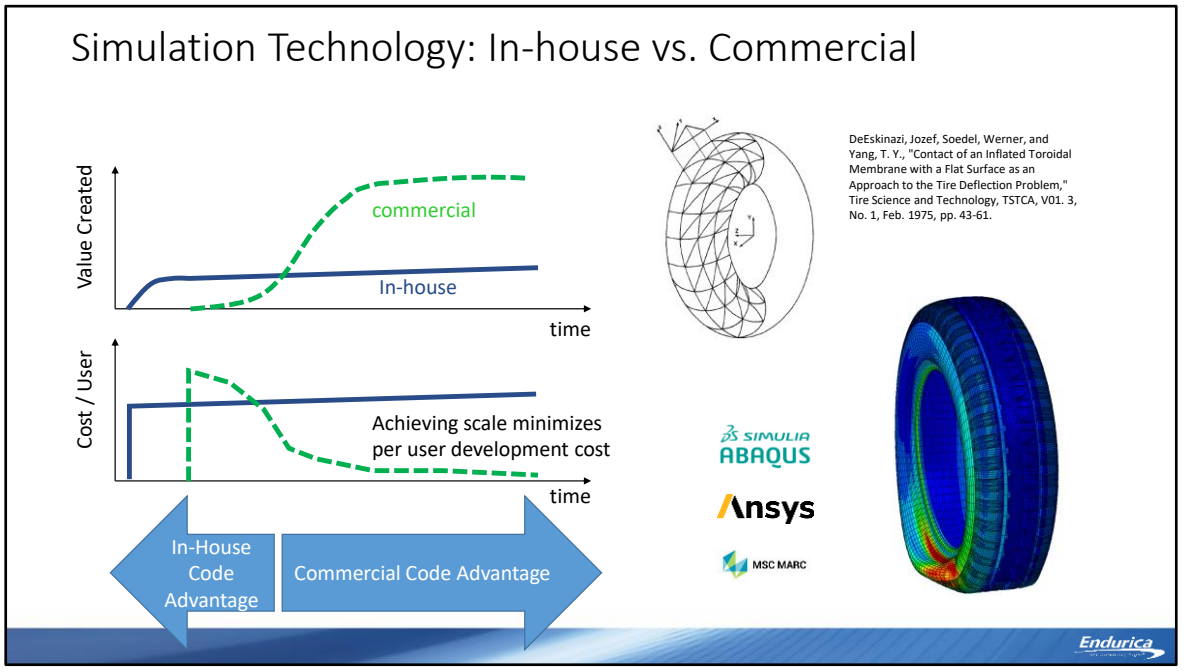
While I was working on this project, John encouraged me to pursue a PhD, which I did at the U of Toledo. This is me right after finishing my PhD. I had resolved not to shave until I finished. LOL

Finite Element Analysis Adoption in the Tire Industry



When I came into the industry, the underlying theory of FEA was starting to be well established, but it had not yet been widely commercialized nor had it yet penetrated into routine tire engineering workflows. Tire companies were all in a race to code their own finite element solvers. The promise was that simulation would let us make quicker, better vetted decisions about tire design.

That vision has largely been realized. No tire company today designs a tire without using FEA.



When I wrote Cooper's thermal FE code, I imagined that we would use it in perpetuity. In fact, they did use it but only for 2 or 3 years. Then this happened: Cooper stopped developing its in-house FE solver in favor of bringing in a commercial code: Abaqus! This was a weighty decision. There was a sizeable development team and there had already been years of investment in developing the in-house solvers and pre/post processing tools. There was a big reorganization that came with this. I remember worrying about this turn of events when it happened. But it was absolutely the right call.

The commercial finite element solver was far more capable, better supported, user friendly, validated than our in-house code. And no wonder – where we only had a small 'sometimes' team writing code for a small user base, the commercial solution had a large dedicated team writing code that was used by a large number of organizations. The cost of the software license was a fraction of one person's salary! You can't justify supporting an inhouse code development group when the commercial code is so cheap and so capable.

One thing I've learned by starting a business is that the purpose of a company is to scale up their solution so that its value creation is maximized. There is obviously a place for in-house technology development if it gives you a competitive advantage that you can scale. But you must be choosy. If you can't scale a technology that your business is using, and if your inhouse solution is not in a position of significant advantage over the commercial solution, then you will be better off in the long run buying from somebody else who IS scaling the technology. They can spread the development cost over a much larger base of users.

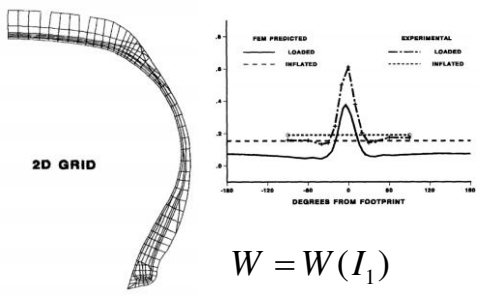
difficulties of internal tech
- too protected so they don't evolve as quickly or completely
- lack of business model
- cost of implementation and support
- turnover
- single point of failure
- dependent on internal politics, which is sometimes too personal and too driven by ladder climbing

How Long Will It Last?

Another big advantage of going with the commercial solver was that it freed us up to finally attack the problems that we really wanted to solve. My research focus went from “how do we compute stress and strain and temperature in a tire” to “how do we use the results of a simulation to predict tire durability”. I ended up choosing this topic for my PhD dissertation and it ended up turning into my entire career so far!

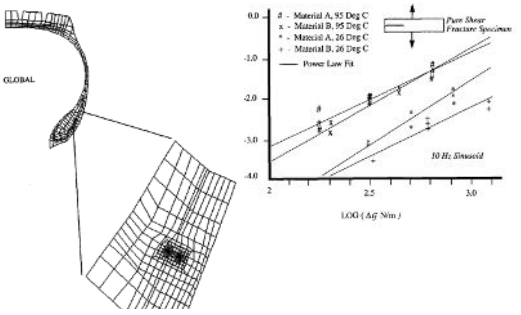
Tire Industry Practices - Pre-Endurica

De Eskinazi, J., Ishihara, K., Volk, H., & Warholic, T. C. (1990). Towards predicting relative belt edge endurance with the finite element method. Tire Science and Technology, 18(4), 216-235. (***46 Cites*** August 2015)



$$W = W(I_1)$$

Ebbott, T. G. (1996). An application of finite element-based fracture mechanics analysis to cord-rubber structures. Tire Science and Technology, 24(3), 220-235. (***46 Cites*** August 2015)



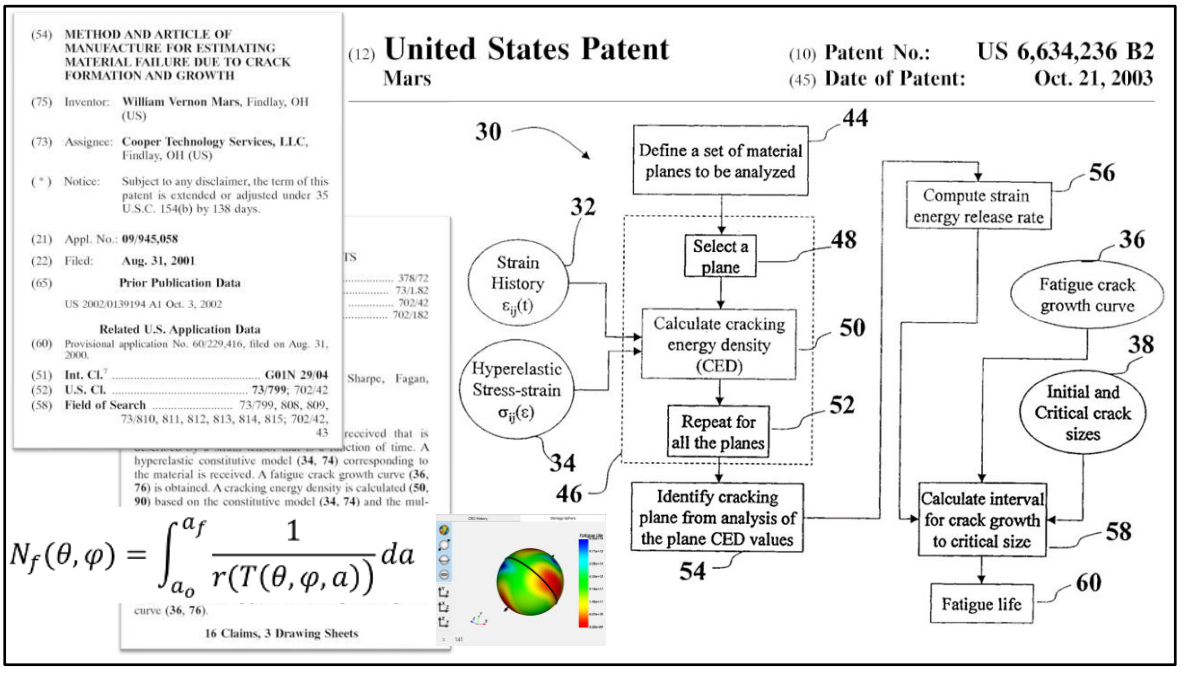
$$T = G = J = -\frac{d(U-V)}{dA}$$

I especially remember two papers that impacted the approach I developed.

Deeskinazi's work advocated looking at strain energy density. This is very easy to get in every element without any special procedures, and also it is very easy to correlate SED to fatigue life for a uniaxial fatigue test. But there was almost no validation that SED would correlate generally with fatigue under multiaxial loading.

Ebbott's work advocated looking at fracture mechanics. This is a proven way to accurately assess the growth of a known crack. But it requires special procedures that are much more expensive. And it only produces information about one crack at a time.

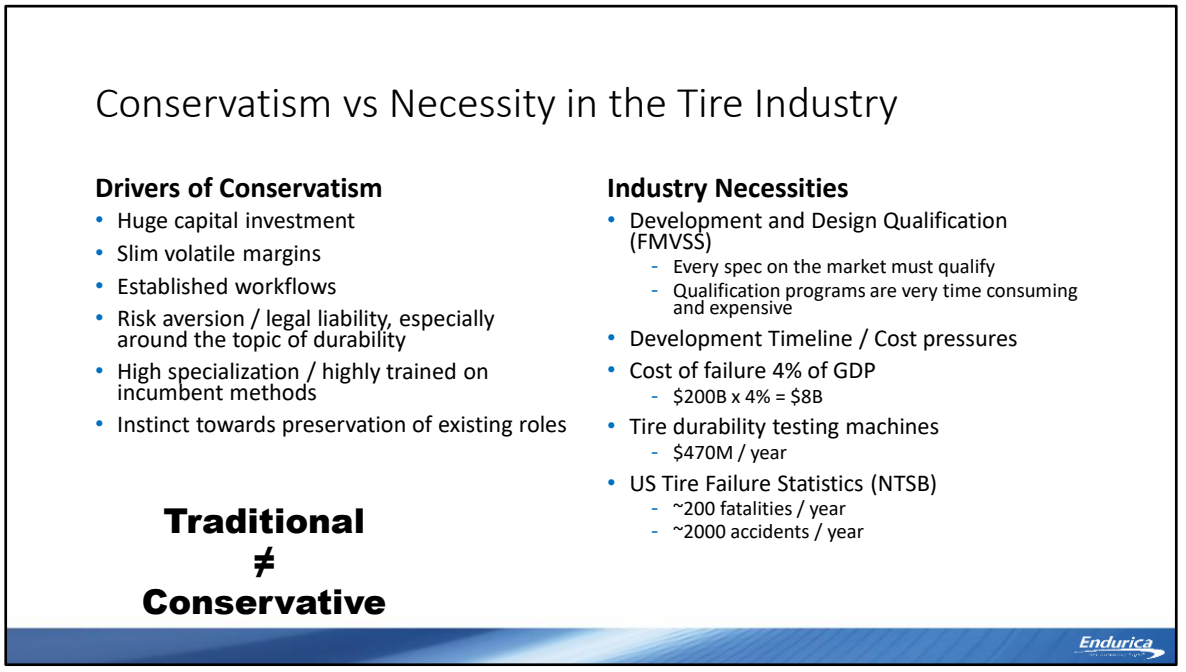
So I chose to focus on the problem of how to estimate fatigue under conditions of multiaxial loading (general combinations of tension or compression with shear). My advisor at UT was Prof. Ali Fatemi, who has expertise in analysis of metal fatigue.



This lead to my invention of the first Critical Plane algorithm for rubber fatigue analysis. The core idea behind critical plane is a 'murphy's law' principle. Cracks are possible in every orientation, so we check all of them. The worst case is always the one that actually happens in practice. We did a huge experimental validation study on this and showed that we could predict not only the fatigue life, but also the crack orientation that would occur under any multiaxial loading scenario.

It was unprecedented at the time, and so we applied for and were granted a patent.

But just because you have a new capability, even when its promising and effective, it does not guarantee that it will be put to good use. The people who own the problem must buy into its solution.



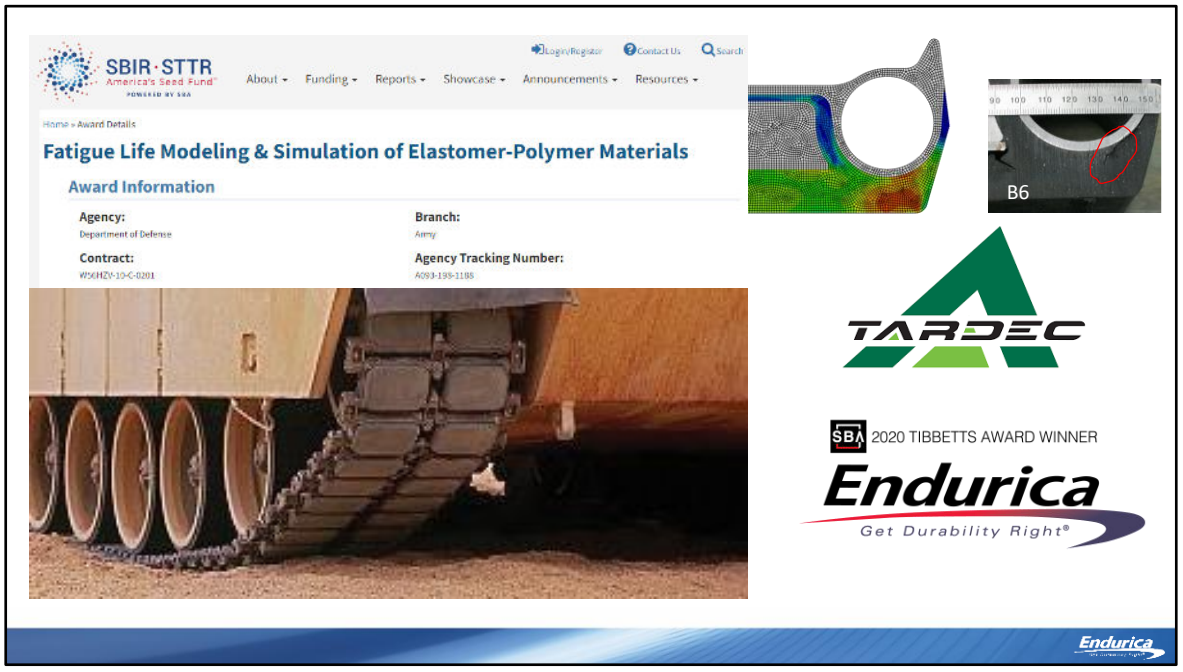
And getting buy-in can be difficult. The tire industry is very conservative for good reasons…

Also, we must differentiate between conservative and traditional. In the case of fatigue analysis, traditional methods were actually LESS conservative than the new Critical Plane Method. Its easy to see this – CP looks at all possible locations and all possible crack orientations. But traditional methods make riskier assumptions: that crack orientation can be assumed without searching, or that a crack is limited to a single location.

Despite conservatism, there are also economic forces that push in the direction of adopting better methods for durability. These forces catalyzed Endurica's eventual incorporation in 2008.

You can't do this kind of thing without the blessing of your bosses, and I must thank my manager Dave Dryden and Cooper VP Chuck Yurkovich, who both supported my initiative in founding Endurica. I remember one moment in particular right after the decision to go ahead was formalized. Dave's first words to me after letting me know of

the decision were “Will you can’t do this alone – get help”. I did take his advice – I approached Rocket Ventures in Toledo – an economic development outfit. They helped me to build my first business plan and to navigate the first steps in commercialization.



Endurica's initial go to market strategy focused on non-tire markets.

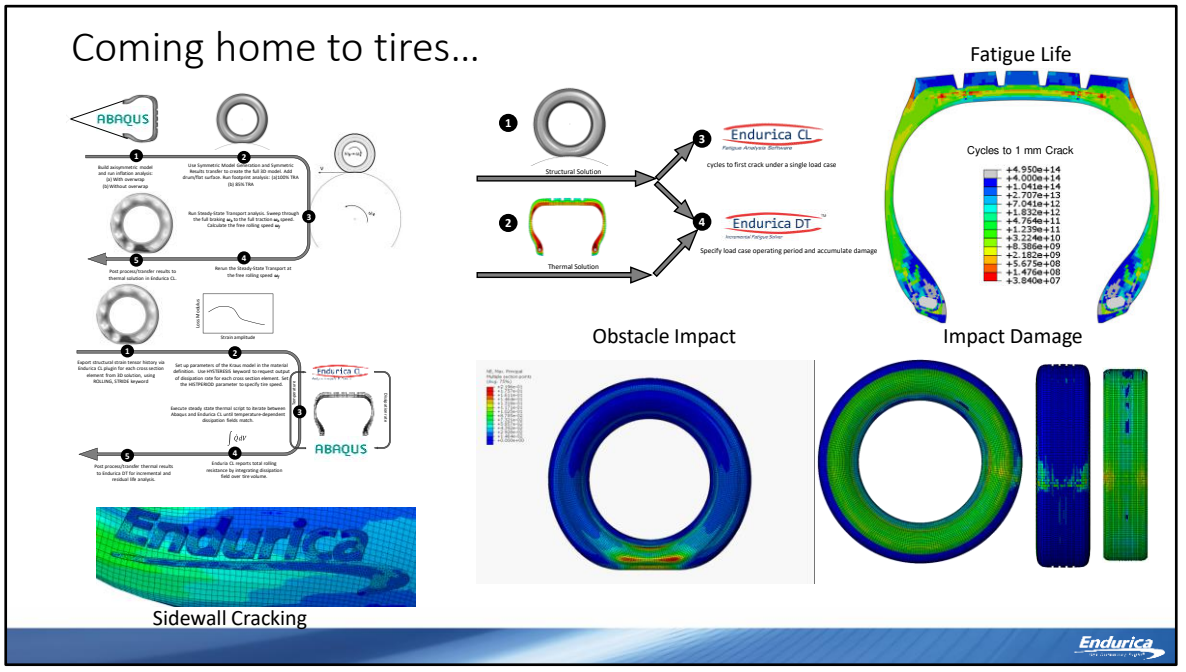
Our first customer was the Army. We won a $730k SBIR contract to analyze durability of tank track pads. A condition of the contract was that I had to trade my comfortable R&D job at Cooper for full time engagement in a startup. This was a place where I had to ask for my wife's blessing to keep going. I have to thank my wife Linda who told me I should go for it, that it was now or never. Her willingness to go on this crazy adventure with me is part of what has made all of this possible.

The contract gave us funding for the first 2 or 3 years, just enough time to build and launch a commercial version of our code. We were able to get into our first distribution agreement with Dassault Systemes.

The Army project was so successful that in 2020 the SBIR program recognized us with their Tibbetts award.

The Army project gave us time to get into automotive bushings and mounts and into other projects. We gained a foothold to survive the end of the Army project and we refined our tools to the point where they would outcompete incumbent/inhouse methods in terms of features, usability and validation case.

As of this year, we've progressed to the point where we are now being used at 13 of the top 20 rubber product makers in the nontire segment as well as many others. We have grown from just me to 9 people on our team.



With these successes under our belt, we then started coming back to tires. Our strategy here has again been to focus on features needed to make tire analysis as simple and as powerful as possible. For example, Endurica can directly use results from a steady state rolling analysis. We expanded our material models to capture effects due to temperature, strain crystallization, ageing and ozone attack. We developed an incremental analysis procedure that allows you to track damage development across a schedule of various load cases. This enabled for the first time a capability to directly simulate regulatory multi-step durability tests such as the FMVSS high speed and durability procedures. Also a capability to study damage caused by transient events such as impacts.

We can now model just about anything you could do to a tire.

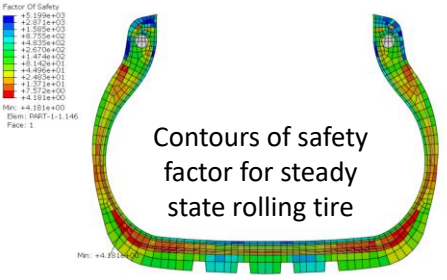
We have also invested in building a strong user experience through interface design, documentation, training. We are now able to deliver our tools and have a new user doing successful tire durability analysis in just a few hours.

Intrinsic Strength Analyser

Endurica is the Americas distributor for

COESFELD MATERIALTEST

- Measures T_0
- Rapid results (1 hour)
- Estimate FCG slope from T_0 and T_c with the Robertson Rule*
- Simple, conservative test
- Simple, conservative analysis
- Avoids complexity of analyzing frequency and temperature dependence



Contours of safety factor for steady state rolling tire

*Rapid Method for Checking Potential for Long-Term Fatigue Performance of Tire Compounds Chris Robertson, ITEC 2018

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Here's another story. If you've been following what we're doing with the ISA, you know that the original experiment came from Graham Lake and Oon Hock Yeoh in the late 70s. It's a method that measures rubber's fatigue limit, and it can give you results in an hour that otherwise would take months. You can use it with Endurica software to compute safety factors for a tire.

I met Oon Hock at a rubber division meeting. We shared an interest in fracture mechanics and he was kind to entertain conversation with a junior me. Once over dinner he shared with me some personal wisdom from the Psalms : "**Teach us to number** our **days**, that we may gain a heart of wisdom". 90:12

Fatigue Crack Growth: Prior Art vs. Endurica method

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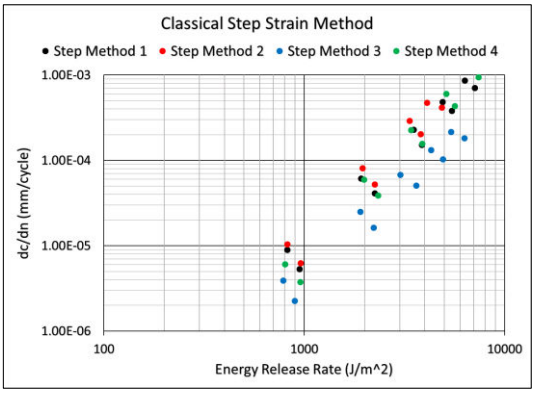
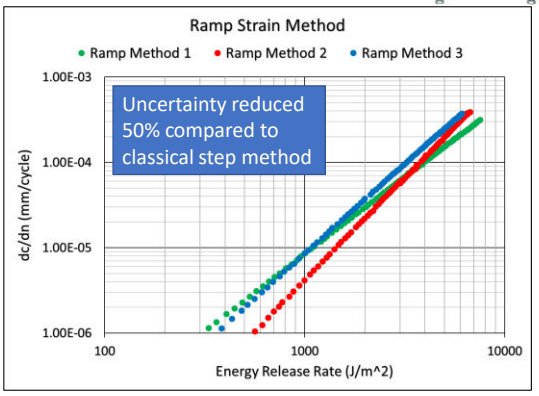
Joshua R. Goossens and William V. Mars (2018) "Finitely Scoped, High Reliability Fatigue Crack Growth Measurements", *Rubber Chemistry and Technology*, in press (https://doi.org/10.5254/rct.18.81532)

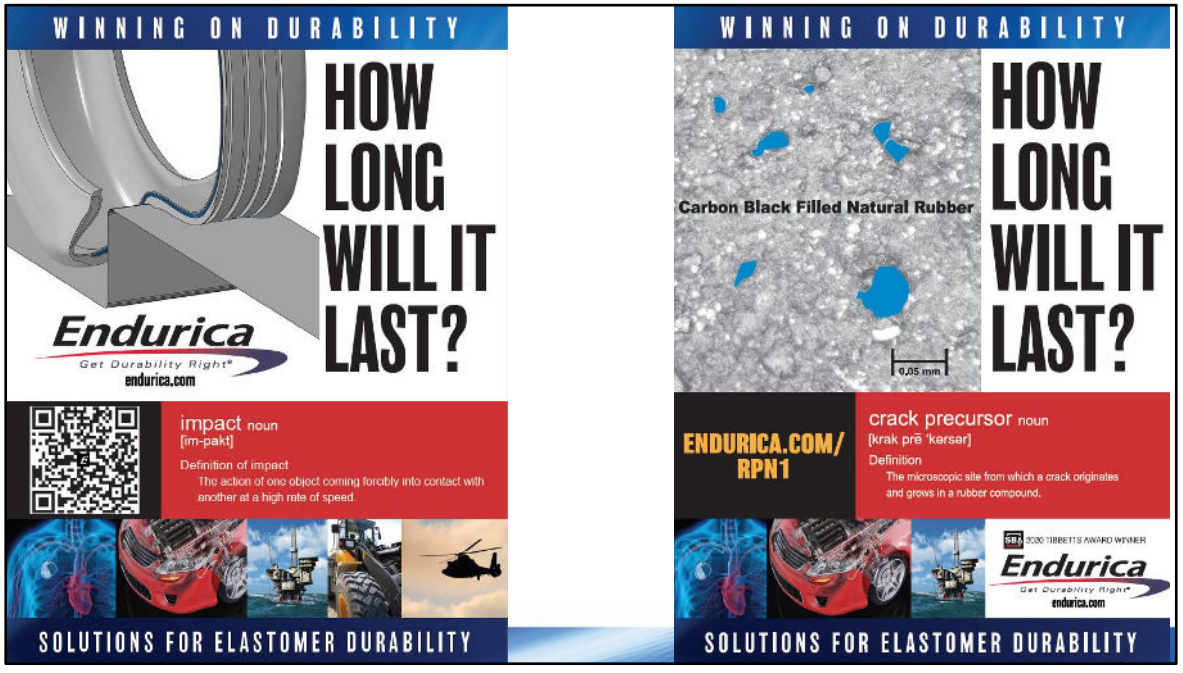




The work we did in resurrecting Yeoh's work attracted the attention of Reinhold Kipscholl, the owner of Coesfeld and developer of the TFA. Our work on IS ultimately led to our partnership with Coesfeld.

I'll also mention an improvement we made to the classical test for measuring crack growth rate curves. The original methods produce data that exhibit large scatter. The scatter makes it harder to resolve differences between compounds and have been a barrier to adoption of this test method. We developed a method that uses a continuous sweep of the strain amplitude. This method is now available as an option on the Coesfeld TFA. We've benchmarked the method and shown that it can reduce noise in the results by 50% compared to the classical method.

If you want to bring these methods to your lab, let me know. Endurica is the Americas distributor for coesfeld.



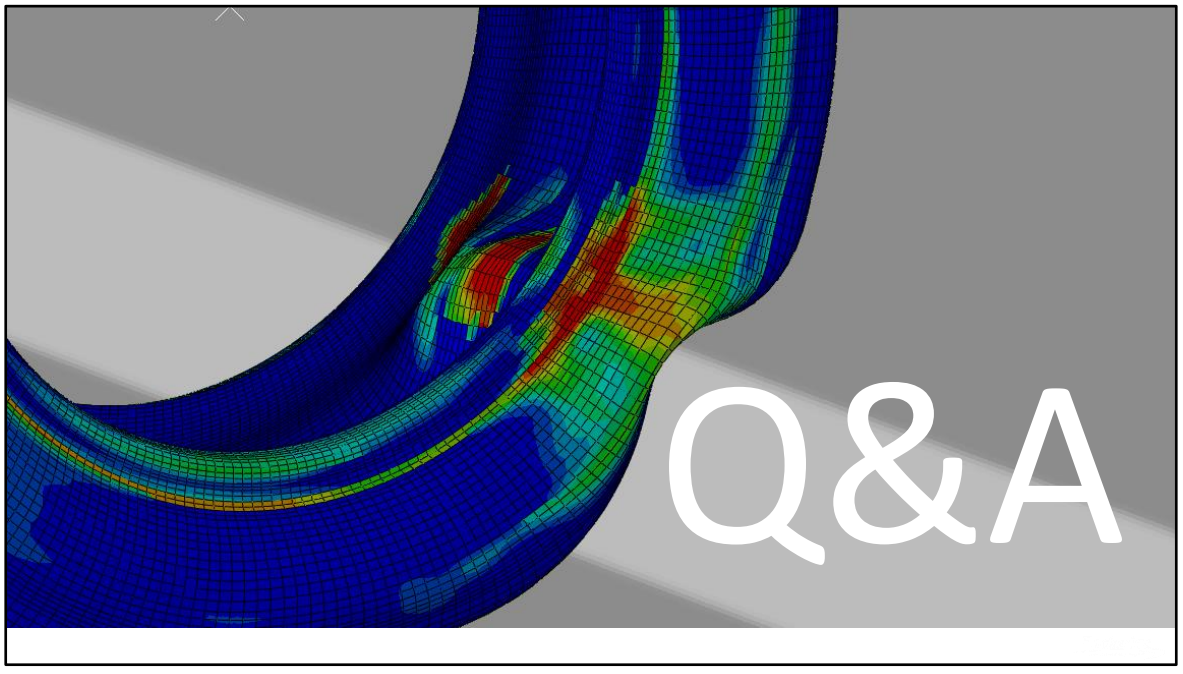
Endurica has come such a long way in 14 years. Again, I'd like to thank the selection committee for recognizing our work and our impact with this award.

I like to think that it marks a transition from a time where we were discovering and articulating the science of durability and its potential to a time where we are starting to take fuller advantage of the power it gives us.

They say that necessity is the mother of invention and that invention is 1% inspiration and 99% perspiration.

I agree.

If you haven't tried our tools yet, check them out. Durability is far too important to neglect from your simulation portfolio. Our simulation workflows will impress and deliver and put your team in a winning position.


Q&A