

What is Accelerated Life Testing (ALT)?

How do we speed up testing?



Workbook

Presented by

Dr Chris Jackson

Reliability engineer



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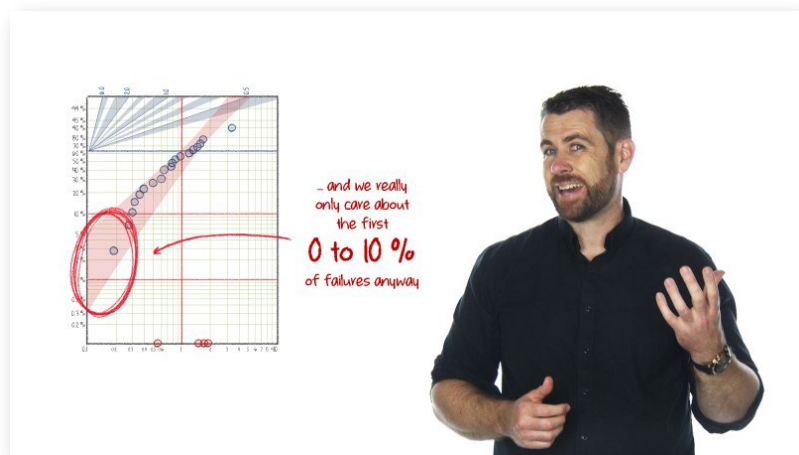
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Who is your teacher? ... Dr Chris Jackson

Dr Jackson holds a Ph.D. and MSc in Reliability Engineering from the University of Maryland's Center of Risk and Reliability. He also holds a BE in Mechanical Engineering, a Masters of Military Science from the Australian National University (ANU) and has substantial experience in the field of leadership, management, risk, reliability and maintainability. He is a Certified Reliability Engineer (CRE) through the American Society of Quality (ASQ) and a Chartered Professional Engineer (CPEng) through Engineers Australia.

Dr Jackson is the cofounder of www.is4.com online learning, was the inaugural director of the University of California, Los Angeles (UCLA's) Center of Reliability and Resilience Engineering and the founder of its Center for the Safety and Reliability of Autonomous Systems (SARAS). He has had an extensive career as a Senior Reliability Engineer in the Australian Defence Force, and is the Director of Acuitas Reliability Pty Ltd.



He has supported many complex and material systems develop their reliability performance and assisted in providing reliability management frameworks that support business outcomes (that is, make more money). He has been a reliability management consultant to many companies across industries ranging from medical devices to small satellites. He has also led initiatives in complementary fields such as systems engineering and performance-based management frameworks (PBMFs). He is the author of two reliability engineering books, co-author of another, and has authored several journal articles and conference papers.

Table of Contents

IMPROVING reliability	5
MEASURING reliability	6
ACCELERATING testing.....	6
it's all about creating a STRAIGHT LINE	8
... what about MORE COMPLEX FAILURE MECHANISMS?	11
... but these are just BEST GUESSES.....	12
... so how did we get this CHEMICAL REACTION ACCELERATED LIFE CHART?.....	13
HIGHLY ACCELERATED LIFE TESTING (HALT) is not ACCELERATED LIFE TESTING (ALT)	14

... measuring ^{or analyzing} reliability CAN be important ...

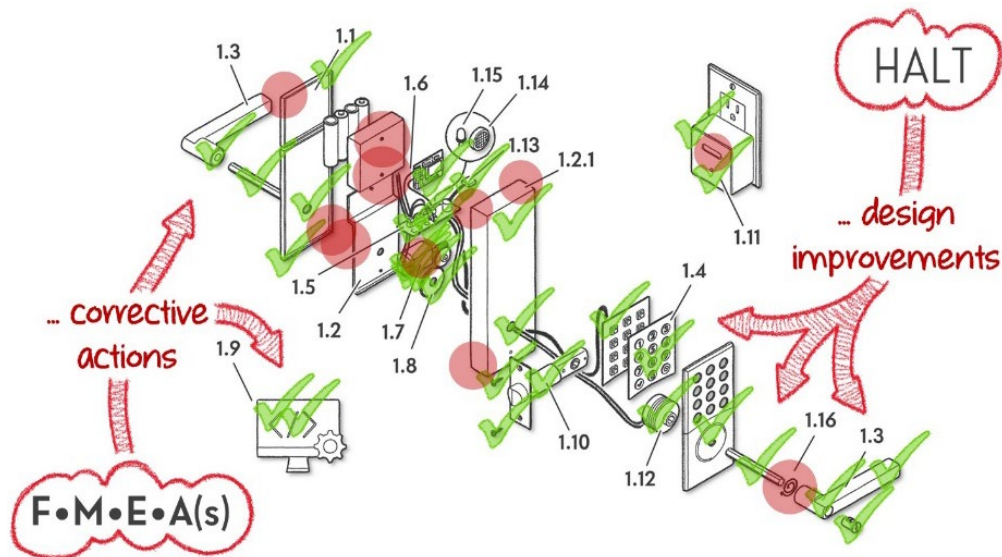
... but not nearly as important as *DESIGNING IN RELIABILITY* ...

Reliability engineering happens when we incorporate simple and effective design characteristics (and **corrective actions**) early. Every problem (no matter how technologically complex your 'thing' is) has a range of solutions. The cheapest and easiest are ALWAYS those that can only be solved using a design characteristic BUILT INTO YOUR FIRST DESIGN.

It is only when you are forced to redesign something without 'affecting' other components that fixes become complex and expensive.

IMPROVING reliability

Activities like **FMEAs** help us prevent problems and weaknesses into our first design. Activities like **HALT** help us find any residual weak areas of our design through fast and cheap testing that is done early enough to allow us to easily fix any underlying issues.



This also means that we are very aware of the residual weak points that we have decided we don't need to address. We know that these will cause our product to eventually **fail**. Which also means we know HOW it will eventually **fail**.

MEASURING reliability

Once we have a robust design, we might need to start measuring **reliability**. We might need to know what materials we should use to ensure our smart lock **reliability** meets **reliability** targets. We might need to then understand what the **warranty reliability** is.

Let's say we have a two-year **warranty period**. One approach to testing the **reliability** of our smart lock prototype is to test lots of them for two years. But...

... we can't test our smart lock for 2 years ...

*... our company won't make any money
from their sale for this 2-year period ...*

... our competitors will dominate the market ...

*... it will be too late to make design changes by then anyway (our design and
manufacturing teams will now be doing something else) ...*

So what can we do?

ACCELERATING testing

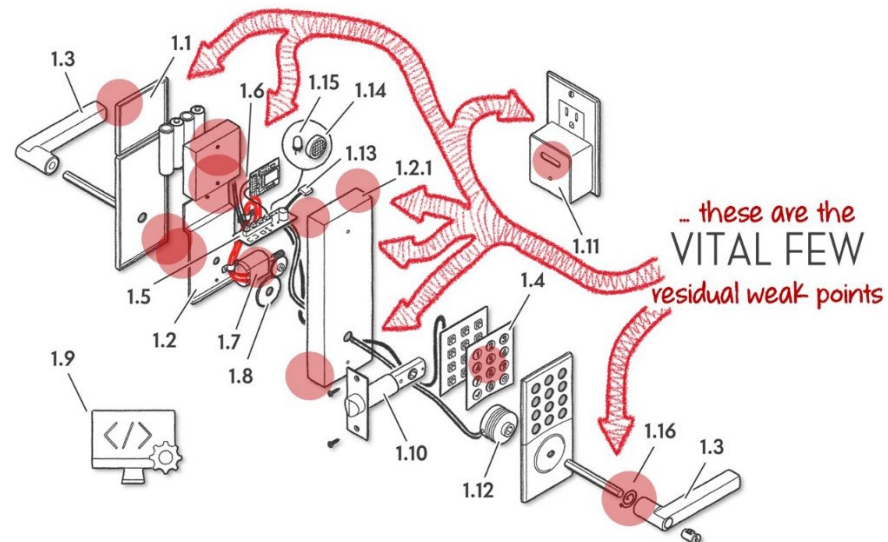
Accelerated Life Testing (ALT) involves increasing one or two stresses accelerate **failure** in a very controlled way to understand the **TTF** in '**operational conditions**.' And this means we need to know what **failure mechanism** we are accelerating, and how increasing stresses makes this **failure mechanism** occur faster.

ALT can be used in a very generic (or 'throwaway') context to simply do testing faster (usually when no one has planned testing properly). There are a several pre-requisites for any successful **ALT** program that must be thoroughly considered.

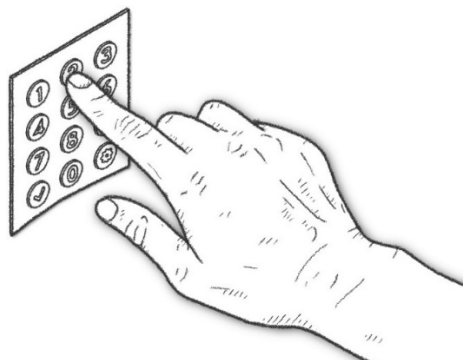
- 1. You must KNOW HOW your product fails. Or ... you must understand the
VITAL FEW weak points of your system*
- 2. You must be able to MODEL HOW your product fails (based on those
VITAL FEW weak points)*
- 3. You must UNDERSTAND THE CONDITIONS in which
your product will normally be used*
- 4. You must not change the CONFIGURATION or
STATE of your product by increasing the stress.*

The last pre-requisite is very important. There is not point in increasing temperature so much that it melts your product melts. This is not a representative failure if your product will never be used in temperatures that cause melting.

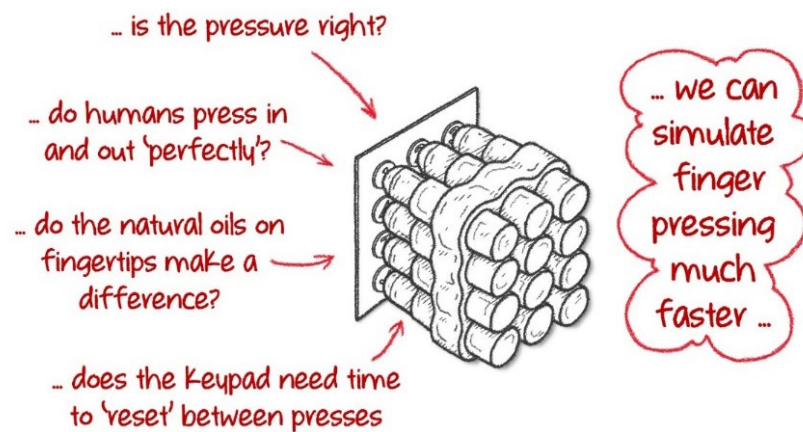
Let' say we know the remaining **VITAL FEW** weak points in our smart lock (or areas that we believe will cause the smart lock to eventually fail.)



One of these weak points resides in the keypad. This doesn't mean that the smart lock is **unreliable**. It simply means that keypad **failure** will likely be one of the likely ways our smart lock will eventually **fail** after a (hopefully) long and successful operational life. So how can we test our keypad by 'mimicking' two years of use to try and understand **warranty reliability**?

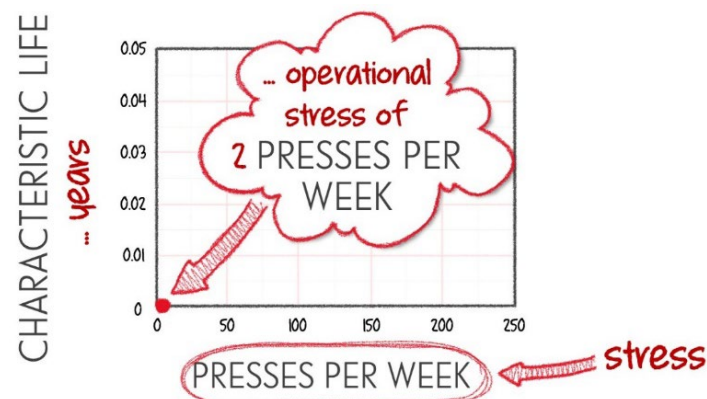


Pre-requisite # 3 is understanding the conditions in which the product will be used. This often involves a use case that involves how often we believe each key will be pressed. Let's say the smart lock use case we develop states that each key on the keypad will be pressed (on average) twice a week. We might be able to build a 'key pressing' test rig to simulate each key being pressed very quickly. You should always be careful that you precisely mimic the real-world conditions ...

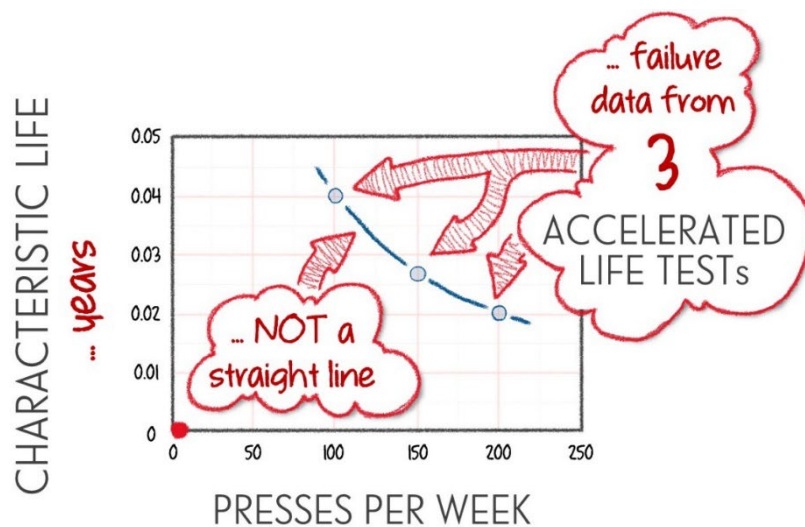


it's all about creating a STRAIGHT LINE

The keypad pressing rig above allows us to increase the **stress** the keypad experiences by increasing the frequency of key presses. We can then test to identify how long it will take to fail at these higher **stresses**. We can use the chart below to visualize these results.

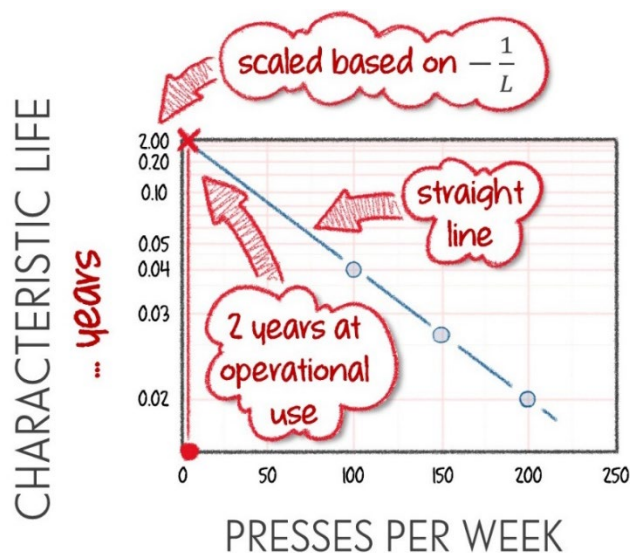


Let's say we picked three higher (**accelerated**) **stresses** and tested our keypad until it **failed**.



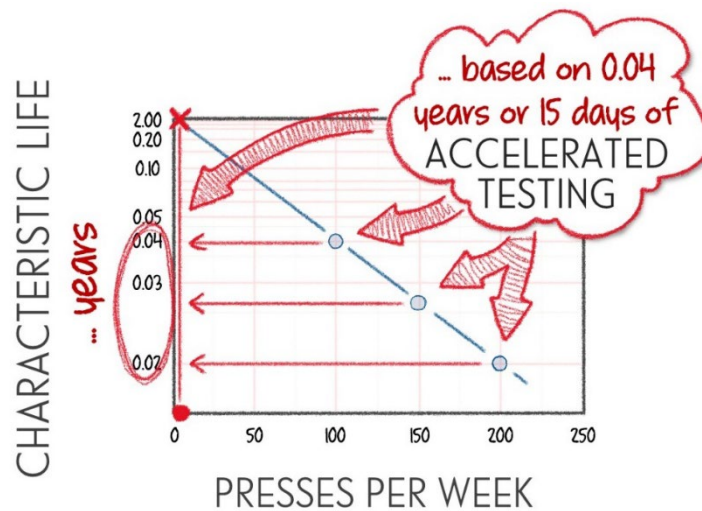
The chart above shows a curved line that correlates **characteristic life** (how long it took for our keypad to **fail**) back to **stress**. We can't project curved lines back to **operational conditions**. We now need to adjust the scales on an **accelerated life chart** to ensure the **failure mechanism** we are investigating creates a straight line. And this means we need to understand the **failure mechanism**.

The chart below is what results when we use a scale based on the negative inverse of the **characteristic life** (L). This is the scale we use for **stresses** based on increasing frequencies.

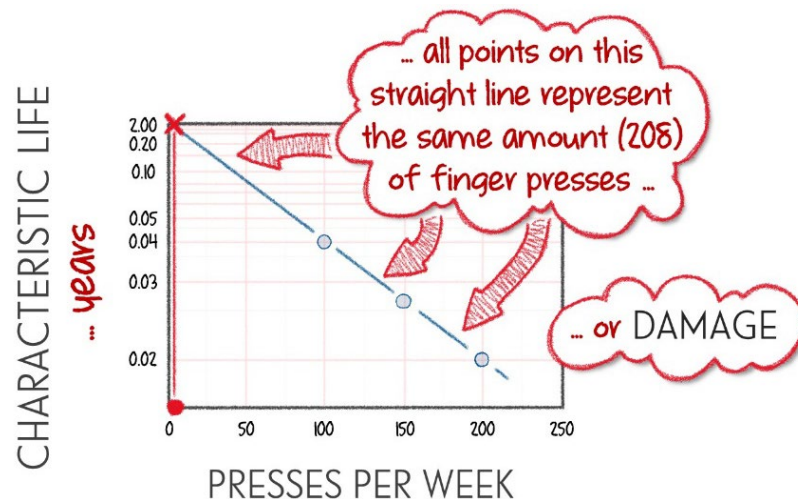


Now we can project this straight line back to **operational conditions** (two presses per week) to see that the **ALT** data suggests our keypad will **fail** at around 2.00 years of operational use. Given that this is also our **warranty period** ... this is bad!

The benefit of **ALT** is that it doesn't take very long to get objective results.



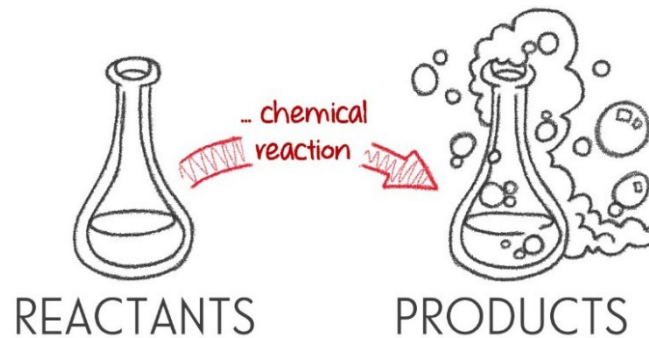
So why did we use the negative inverse of the **characteristic life** (L)?



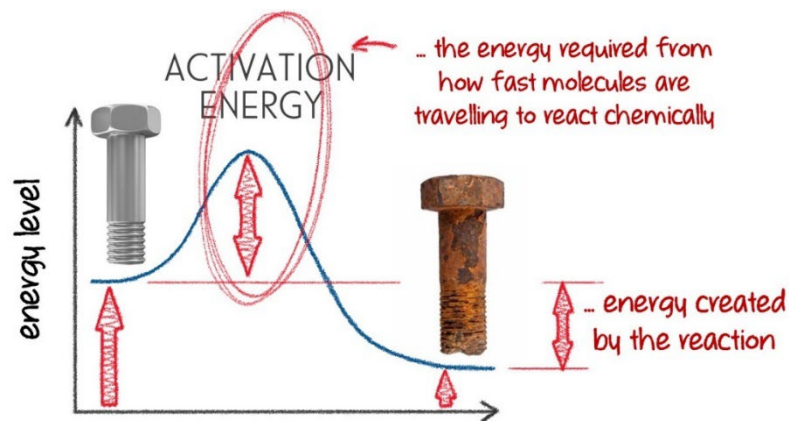
Every failure mechanism we can model creates an **accelerated life chart** (like the one above) where test data will create a straight line. If we assume a **failure mechanism** and the **ALT** data does not create a straight line, then either our product is failing due to another **failure mechanism** or we don't understand the assumed **failure mechanism** well enough.

... what about MORE COMPLEX FAILURE MECHANISMS?

Many **failure mechanisms** are based on **chemical reactions** (like **corrosion** and **diffusion**.) We know that one of the ways our keypad might fail is due to **rubber degradation**, which is a **chemical reaction**. So what happens in a **chemical reaction**?

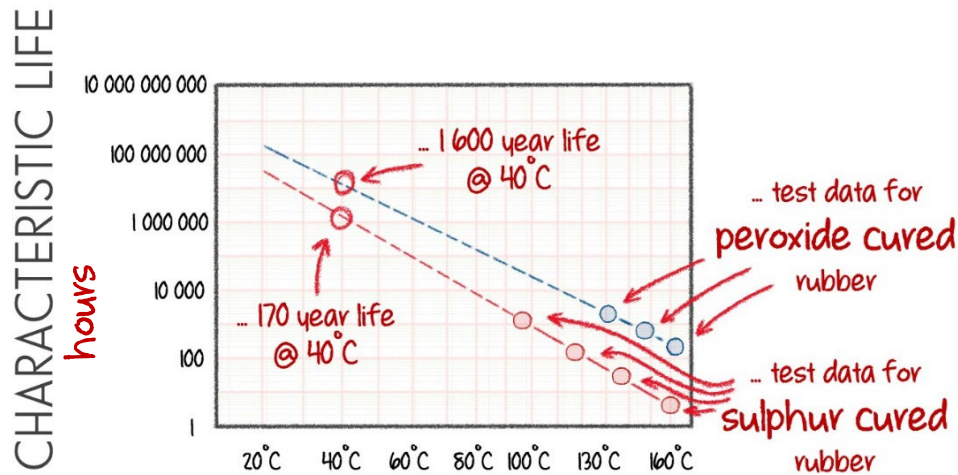


Reactants 'want' to become **products**. **Products** exist in a lower energy state which is where everything wants to go (like a ball 'wanting' to roll down a hill.) **Chemical reactions** involve a barrier for the **reactant** to turn into a product, and that barrier requires at least some initial energy.



To speed up **chemical reactions**, we need to give more energy to the **reactant**, usually by increasing temperature (which makes the molecules vibrate faster with more energy.)

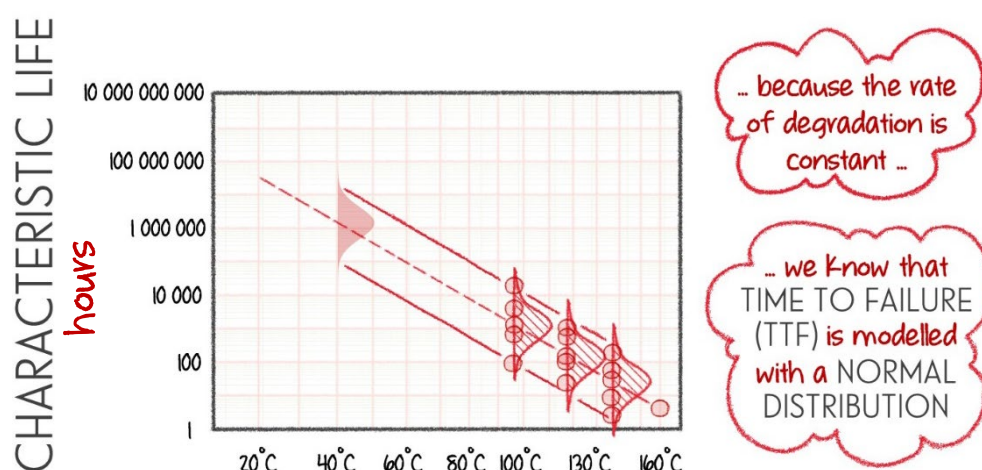
Chemical reactions have a well-known **accelerated life chart** called an **Arrhenius Plot** where the **accelerated stress** is temperature. The vertical (**characteristic life**) axis is scaled logarithmically, and the horizontal (**stress** or temperature) axis is scaled using a negative inverse. This allows us to compare different rubbers to help us select the one that is the most robust for our smart lock.



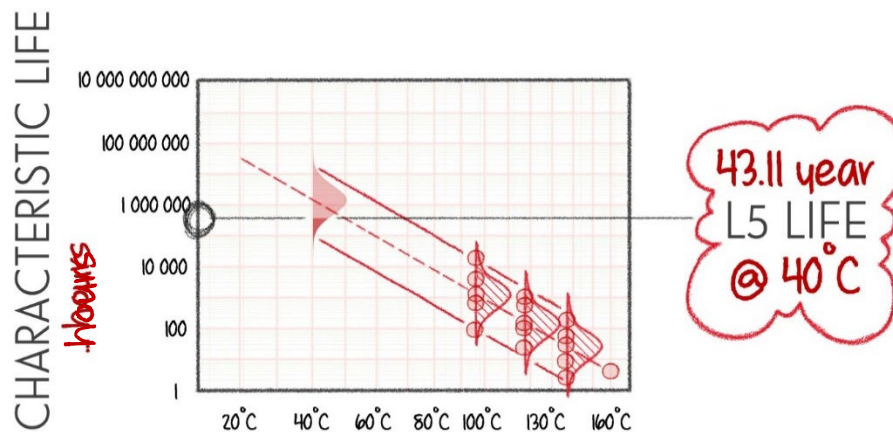
... but these are just BEST GUESSES

The best guess at **TTF** (like the mean or **MTTF**) can be useful if we are trying to work out which rubber will generally last longer. Let's say the peroxide cured rubber (which the ALT data above suggests will last longer) is significantly more expensive. The 'best guess' 170-year life of the sulphur cured rubber is 'good,' but we also know some rubber products will **fail** before 170 years. Some will **fail** after. How far 'before' 170 years will the first products **fail**?

We can test multiple rubber samples at increased (or **accelerated**) stresses to fit a **probability curve** that can also be projected back to real world conditions.



The 'bell curve' at 40 °C on the previous chart allows us to calculate the time by which we expect 5 % of our rubber components to fail (also known as the 'L5 life').



... so how did we get this CHEMICAL REACTION ACCELERATED LIFE CHART?

It starts with knowing HOW your component will fail. There is a well-known model (**Arrhenius model**) that relates the increased temperature to rate of **chemical reaction**.

ACTIVATION ENERGY

$$k = Ae^{-\frac{E_a}{kT}}$$

... the rate of the reaction (which is the frequency of collisions that have enough energy to cause the chemical reaction) → k

... constant for each chemical reaction → A

... Boltzmann's constant $1.3806504 \times 10^{-23}$ Joules per Kelvin → k

temperature in degrees Kelvin → T

... E_a → ACTIVATION ENERGY

We can rearrange this equation to get ...

$$\frac{C}{L} = Ae^{-\frac{E_a}{kT}}$$

... some constant → C

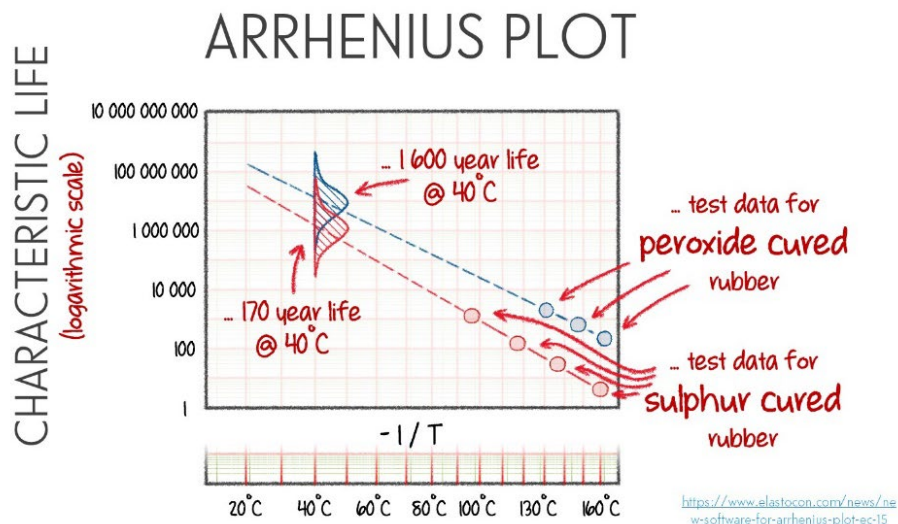
... the CHARACTERISTIC LIFE → L

And we can rearrange it further to get ...

$$\ln L = \ln c - \ln A + \frac{E_a}{k} \left(\frac{1}{T} \right)$$

... the reason we did this was because we can now create a straight line (.. even if this is not obvious right now)

You can see that the left-hand side of the equation is in terms of the logarithm of the **characteristic life** (hence the logarithmic scale of the vertical axis). You can see that on the right-hand side, the equation for the straight line is in terms of the inverse of the temperature. To ensure that the temperature increases along the horizontal axis (as this aligns with how we view most charts), we make this a negative inverse scale. You can see this scale superimposed on the horizontal axis below in addition to temperature.



Because the data creates a straight line, the **Arrhenius model** appears to be a good fit.

HIGHLY ACCELERATED LIFE TESTING (HALT) is not ACCELERATED LIFE TESTING (ALT)

ALT is all about increasing a **stress** to decrease the **TTF** in a **reliability test** to understand what the **TTF** would be in '**operational conditions**.' This must be done in a 'scientific' way. The pre-requisites for **ALT** ensure we focus on usually one **failure mechanism** that we have determined is a likely weak point of our product, and something we have modelled.

HALT is really helpful at finding those VITAL FEW weak points (and their **failure mechanisms**) that we either design out of our product, or can conduct **ALT** on to understand how long it will take for that **failure mechanism** to cause **failure**.

While both tests are relatively short, **ALT** will typically take longer than **HALT**. **HALT** can be completed in hours. **ALT** can sometimes take weeks. **HALT** will give you a list of the VITAL FEW weak points. **ALT** focuses on a very scientific analysis of one of these VITAL FEW. So even though they sound the same, they have very different roles and outputs.