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1 Introduction

This report aims to provide the reader with insight on material testing and characteristics. This is to be achieved by demonstrating knowledge gained through research and reading, along with details of an experiment that has personally been conducted. Ultimately, the report will conclude with an analysis of material failure in a motorsport context.

2 Literature review

Materials are often spoken about with reference to their 'properties'. These labels indicate how a material typically behaves and can help to establish applicable use cases during a material selection process. Some common properties and their descriptions are listed below:

- **Strength-** often split into three categories (tensile, shear and compressive. This property indicates the absolute maximum stress a material can endure before failure. A strong material is essential for any component that will be subjected to increased levels of stress.
- **Ductility-** ductile materials possess the ability to deform greatly before fracture. Copper is a notable ductile material. An example of where utilisation of a ductile material can be found is in steel tire bead wires where the material is required to stretch and in copper wiring (Su and Shemenski, 2009).
- **Brittleness-** a brittle material will characteristically fail with very little deformation. This can essentially be seen as the opposite to ductility. Ceramics are known to be brittle yet very strong, showcasing the common link between the two properties.
- **Toughness-** the capability of a material to retain integrity when subjected to force. These materials are often also ductile as they can plastically deform with relative ease prior to fracture with copper and steel once again being examples. Tough materials are often essential for structural integrity and safety meaning they can be found in places such as airframe and wing structures (Haleem et al., 2023).

To determine what properties a material may possess, numerous physical testing methods exist. The results of which help to determine overall material characteristics, thereby enabling the ability to label given materials to quickly

and accurately convey how they are expected to behave. The testing methods for the discussed properties can be seen below:

- Strength- naturally, there are different tests for the different types of strength. The tensile test consists of a uniform section of material being subjected to tensile load until failure. More details regarding the procedure can be seen in section 3.

Shear testing utilises a universal testing machine which is able to subject the sample to pre-determined loads depending on intended use case. This aims to reproduce stresses the material will be faced with when in application. The machine will record data regarding material performance and visual observations will be made regarding appearance post-test (McClements and Demirel, 2024).

Compression testing simply consists of a uniform material being compressed between plates until cracks form (ductile) or failure (brittle). Often, a machine will log data during the test which can then be plotted for compressive capabilities to be observed and evaluated.

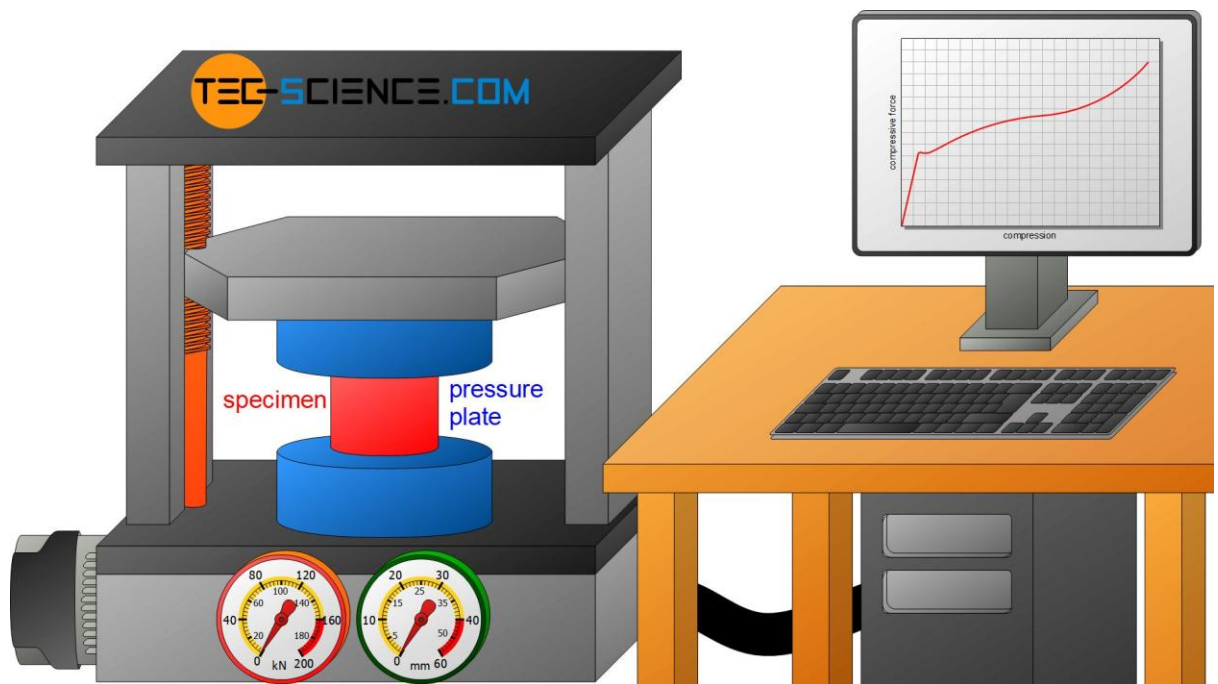


Figure 1- Setup for Compression Test (TecScience, 2018a)

- Though ductility is often tested using the aforementioned tensile test, other methods such as the cupping test allow ductility to be evaluated. Often used for testing sheet metal, the cupping test sees a ball being pushed into the sample with increasing force. The depth at which the material can support the ball before cracking allows the ductility to be measured and assessed (Erichsen, 2025).
- Brittleness & Toughness- both of these properties can be assessed using the Charpy impact test. This test consists of a material sample with a V-shaped cutout being placed so that a pendulum hammer may strike it. (TWI The Welding Institute, 2019). Brittleness may be calculated based on the reaction of the material to being struck as they will break with very little deformation. Tough materials on the other hand are expected to noticeably deform prior to failure. The height the hammer achieves after the initial strike reveals additional information on how materials are able to absorb the force exerted on them. Tough materials will absorb more force, and the hammer will not rise as high, in contrast, brittle materials will likely send the hammer near to its original starting point (TecScience, 2018a).

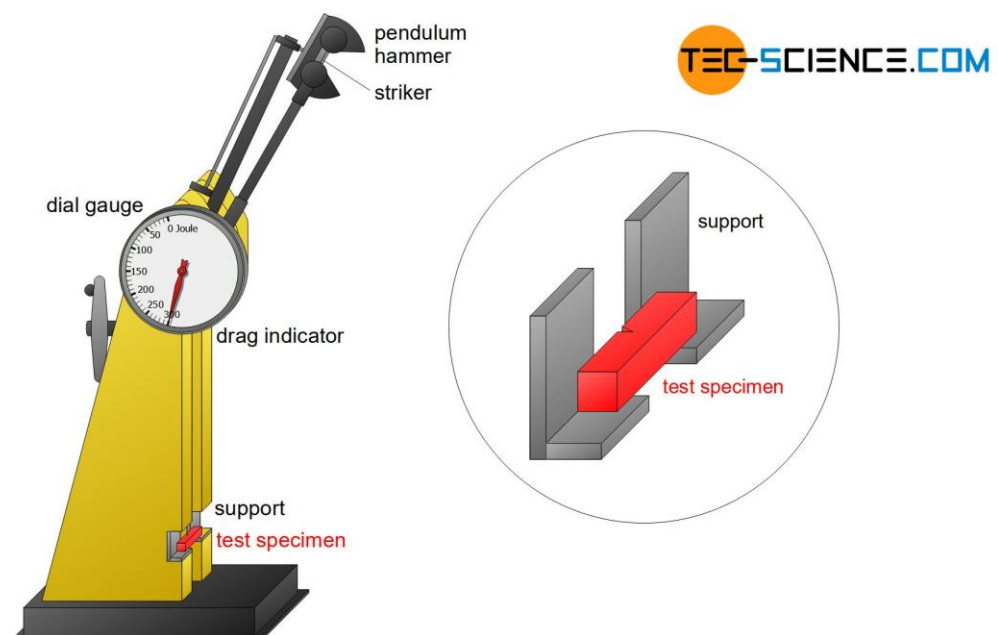


Figure 2- Test Setup for Charpy Impact Test (TecScience, 2018c)

3 Methodology

The methodology and equipment for this experiment was supplied by TecQuipment Ltd as part of the 'Tensile Tester Kit ES6' (2012b). Its details will be outlined below:

1. Attach the Tensile Tester to the work panel.

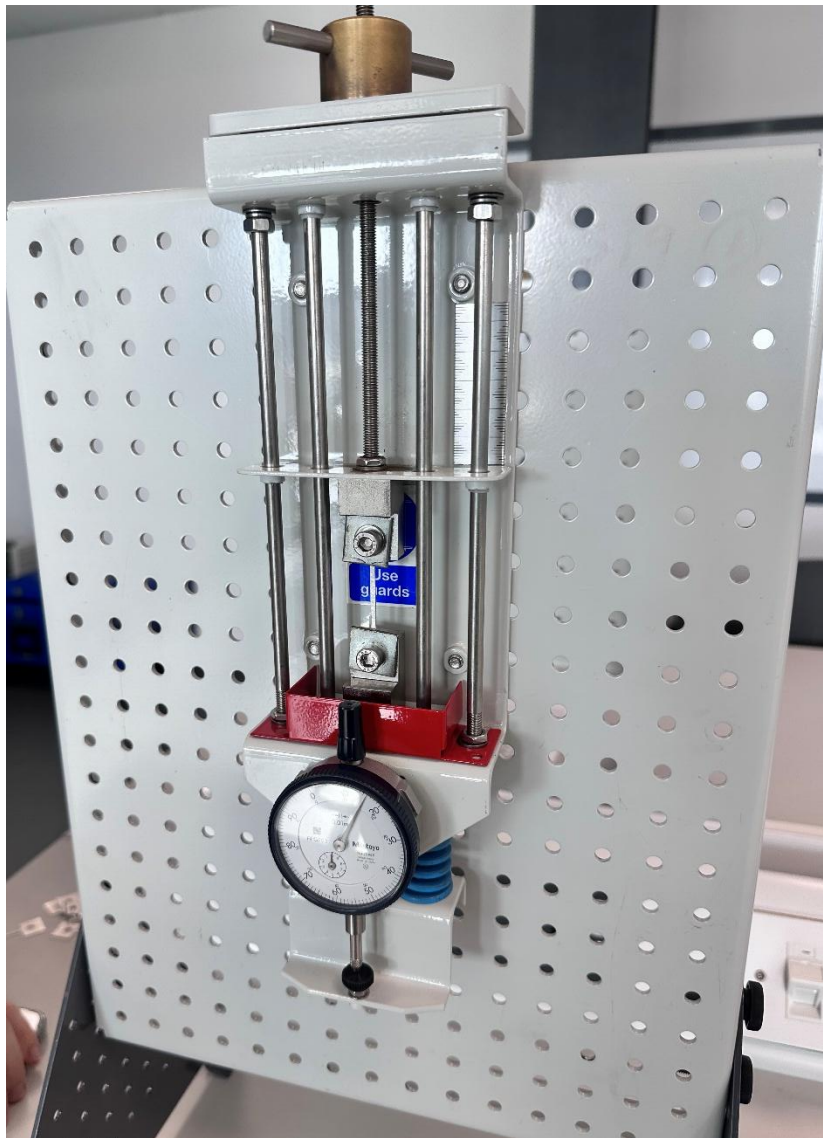


Figure 3- Work Panel with Attached Tensile Tester and Specimen

2. Retrieve the specimen that is to be tested. Measure and record its dimensions including length, thickness and width. This will be required to calculate cross sectional area; a key value for future calculations.
3. Fit the specimen to the testing apparatus using the provided fixings and tool. Ensure the specimen is fully secured before proceeding.

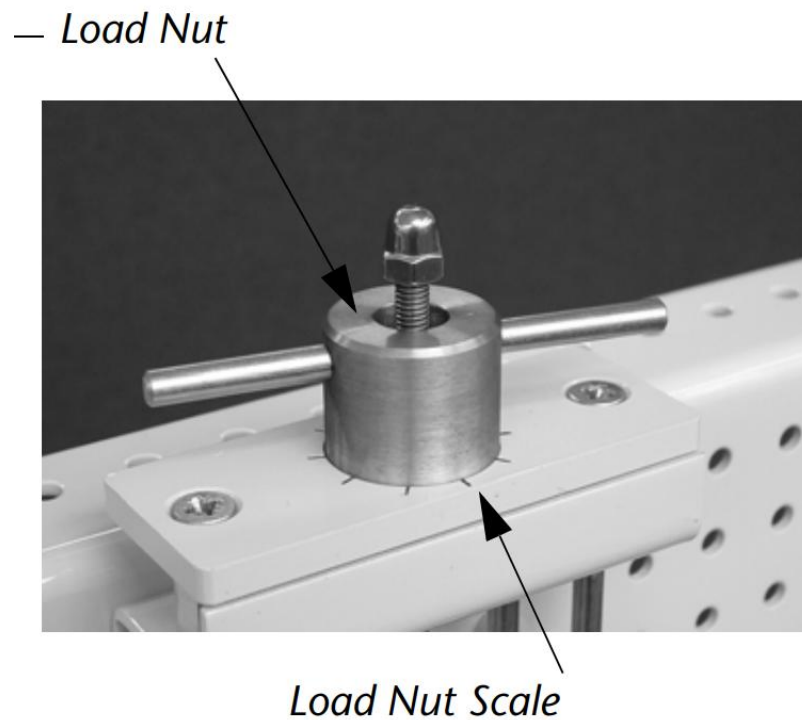


Figure 4- Load Nut and Scale at Top of Apparatus (TecQuipment Ltd., 2012a)

4. Very carefully turn the load nut (seen in Figure 4) until a movement can be seen on the dial indicator (seen in figure 5). Set the dial indicator to zero when this movement occurs. The load nut should align with one of the markings seen at the top of the setup.

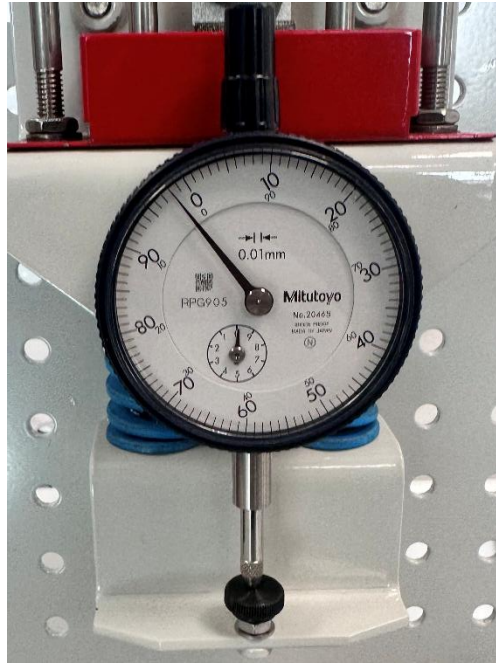


Figure 5- The Dial Indicator Used in the Experiment

5. Understand that each marking on the load nut is equal to 1mm of upward pull.
Turn the load nut a 2mm increment. Record the number seen on the dial indicator.
6. Repeat step 5 until the specimen fails, ensuring to carefully record the dial indicator values at each step.



Figure 6- An Unused Specimen Vs a Tested Specimen

4 Test Results

Table 1- Raw Experimental Data

Specimen material: Original cross-sectional area (mm ² or m ²): Original Length (mm):					
1mm thick 2mm width 30.9					
Load Nut movement (mm)	Dial Indicator (mm)	Force (N)	Extension (mm)	Stress σ N/m ²	Nominal Strain ϵ
0	0				
0.2	0.16				
0.4	0.34				
0.6	0.51				
0.8	0.69				
1.0	0.87				
1.2	1.05				
1.4	1.2				
1.6	1.37				
1.8	1.54				
2.0	1.7				
2.2	1.86				
2.4	2.05				
2.6	2.2				
2.8	2.35				
3.0	2.45				
3.2	2.57				
3.4	2.69				
3.6	2.74				
3.8	2.81				
4.0	2.89				
4.2	2.95				
4.4	2.97				
4.6	3.04				
4.8	2.97				
5.0					
6.0					
7.0					

The above table details the recorded readings from the experiment. Using the values obtained from the dial indicator and the measured specimen dimensions, the data was able to be post processed in Excel.

Table 2- Post Processed Data Table Including Force

Load Nut Movement <i>mm</i>	Dial Indicator	Force <i>N</i>
0	0.00	0
0.2	0.16	16
0.4	0.34	34
0.6	0.51	51
0.8	0.69	69
1	0.87	87
1.2	1.05	105
1.4	1.20	120
1.6	1.37	137
1.8	1.54	154
2	1.70	170
2.2	1.86	186
2.4	2.05	205
2.6	2.20	220
2.8	2.35	235
3	2.45	245
3.2	2.57	257
3.4	2.65	265
3.6	2.74	274
3.8	2.81	281
4	2.89	289
4.2	2.95	295
4.4	2.97	297
4.6	3.04	304
4.8	2.97	297

Force was simply calculated by multiplying the dial indicator values by 100.

Table 3- Post Processed Data Table Including Extension

Load Nut Movement <i>mm</i>	Dial Indicator	Force <i>N</i>	Extension <i>mm</i>
0	0.00	0	0.00
0.2	0.16	16	0.04
0.4	0.34	34	0.06
0.6	0.51	51	0.09
0.8	0.69	69	0.11
1	0.87	87	0.13
1.2	1.05	105	0.15
1.4	1.20	120	0.20
1.6	1.37	137	0.23
1.8	1.54	154	0.26
2	1.70	170	0.30
2.2	1.86	186	0.34
2.4	2.05	205	0.35
2.6	2.20	220	0.40
2.8	2.35	235	0.45
3	2.45	245	0.55
3.2	2.57	257	0.63
3.4	2.65	265	0.75
3.6	2.74	274	0.86
3.8	2.81	281	0.99
4	2.89	289	1.11
4.2	2.95	295	1.25
4.4	2.97	297	1.43
4.6	3.04	304	1.56
4.8	2.97	297	1.83

Extension of the specimen was calculated by subtracting the dial indicator reading from the load nut value for each step.

Table 4- Post Processed Data Table Including Stress

Load Nut Movement <i>mm</i>	Dial Indicator	Force <i>N</i>	Extension <i>mm</i>	Stress(σ) <i>N/m²</i>
0	0.00	0	0.00	0.00
0.2	0.16	16	0.04	8000000.00
0.4	0.34	34	0.06	17000000.00
0.6	0.51	51	0.09	25500000.00
0.8	0.69	69	0.11	34500000.00
1	0.87	87	0.13	43500000.00
1.2	1.05	105	0.15	52500000.00
1.4	1.20	120	0.20	60000000.00
1.6	1.37	137	0.23	68500000.00
1.8	1.54	154	0.26	77000000.00
2	1.70	170	0.30	85000000.00
2.2	1.86	186	0.34	93000000.00
2.4	2.05	205	0.35	102500000.00
2.6	2.20	220	0.40	110000000.00
2.8	2.35	235	0.45	117500000.00
3	2.45	245	0.55	122500000.00
3.2	2.57	257	0.63	128500000.00
3.4	2.65	265	0.75	132500000.00
3.6	2.74	274	0.86	137000000.00
3.8	2.81	281	0.99	140500000.00
4	2.89	289	1.11	144500000.00
4.2	2.95	295	1.25	147500000.00
4.4	2.97	297	1.43	148500000.00
4.6	3.04	304	1.56	152000000.00
4.8	2.97	297	1.83	148500000.00

Stress(σ) was calculated using the following formula:

$$\text{Stress} = \frac{\text{Force}}{\text{Cross Sectional Area}} \text{ OR } \sigma \text{ [N/m}^2\text{]} = \frac{F \text{ [N]}}{A \text{ [m}^2\text{]}}$$

Stress was then converted to MPa from N/m² using the following formula:

$$\sigma \text{ [MPa]} = \frac{\sigma \text{ [N/m}^2\text{]}}{1 \times 10^6}$$

Table 5 - Fully Complete Post Processed Data Table Including Strain

Load Nut Movement <i>mm</i>	Dial Indicator	Force <i>N</i>	Extension <i>mm</i>	Stress(σ) <i>N/m²</i>	Stress(σ) <i>MPa</i>	Nominal Strain (ϵ) -
0	0.00	0	0.00	0.00	0.00	0.0000
0.2	0.16	16	0.04	8000000.00	8.00	0.0013
0.4	0.34	34	0.06	17000000.00	17.00	0.0019
0.6	0.51	51	0.09	25500000.00	25.50	0.0029
0.8	0.69	69	0.11	34500000.00	34.50	0.0035
1	0.87	87	0.13	43500000.00	43.50	0.0042
1.2	1.05	105	0.15	52500000.00	52.50	0.0048
1.4	1.20	120	0.20	60000000.00	60.00	0.0065
1.6	1.37	137	0.23	68500000.00	68.50	0.0074
1.8	1.54	154	0.26	77000000.00	77.00	0.0084
2	1.70	170	0.30	85000000.00	85.00	0.0097
2.2	1.86	186	0.34	93000000.00	93.00	0.0110
2.4	2.05	205	0.35	102500000.00	102.50	0.0113
2.6	2.20	220	0.40	110000000.00	110.00	0.0129
2.8	2.35	235	0.45	117500000.00	117.50	0.0145
3	2.45	245	0.55	122500000.00	122.50	0.0177
3.2	2.57	257	0.63	128500000.00	128.50	0.0203
3.4	2.65	265	0.75	132500000.00	132.50	0.0242
3.6	2.74	274	0.86	137000000.00	137.00	0.0277
3.8	2.81	281	0.99	140500000.00	140.50	0.0319
4	2.89	289	1.11	144500000.00	144.50	0.0358
4.2	2.95	295	1.25	147500000.00	147.50	0.0403
4.4	2.97	297	1.43	148500000.00	148.50	0.0461
4.6	3.04	304	1.56	152000000.00	152.00	0.0503
4.8	2.97	297	1.83	148500000.00	148.50	0.0590

Nominal Strain was calculated by dividing Extension by the original length of the specimen.

$$\text{Nominal Strain } (\epsilon) = \frac{\text{Extension [m]}}{\text{length [m]}}$$

It should be noted at this point that it is impossible to calculate true strain with the provided apparatus. The nominal values seen will provide a reasonable trend to be observed, though any calculations using these values can be deemed as inaccurate.

Using the values seen in the table above, it is now possible to plot a Stress-strain curve.

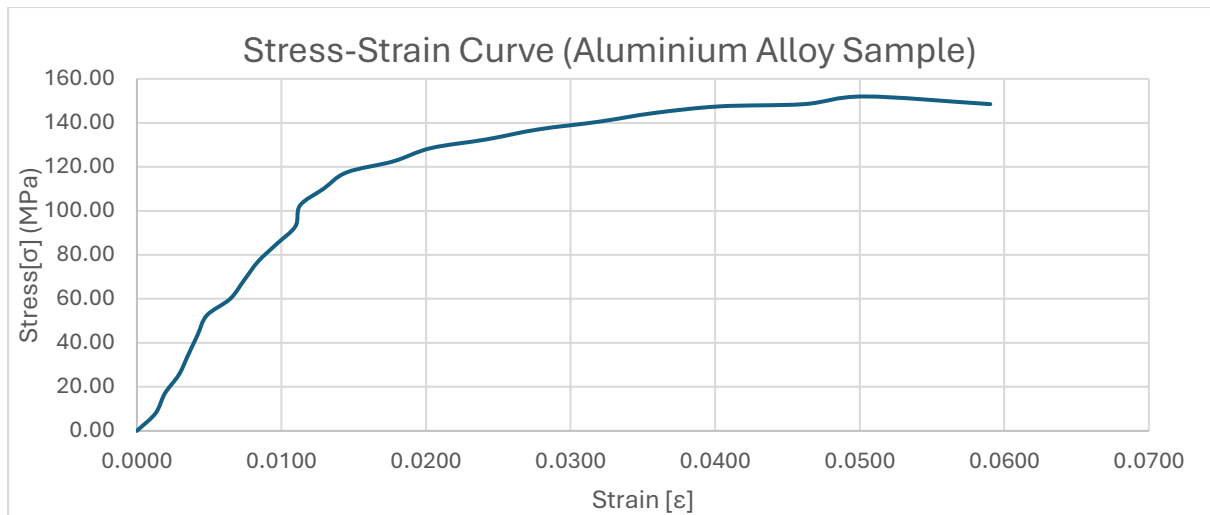


Figure 7 - Stress-Strain Curve Based on Post-Processed Data

This visualisation can help to distinguish an overall trend and extract data points to further evaluate material behaviour (e.g. long plastic region indicates ductility).

5 Analysis

Using the post-processed data discussed in Section 4, values for the material's yield strength, ultimate tensile strength and Young's Modulus can be produced.

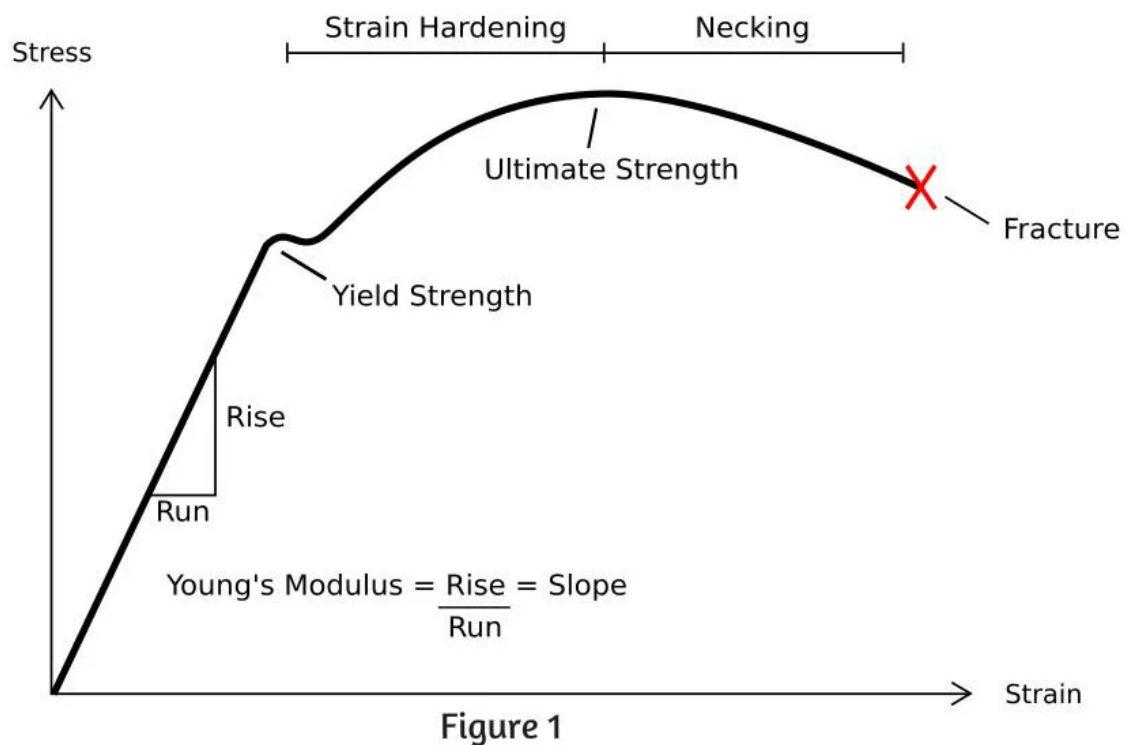


Figure 8- A Labelled Stress-Strain Curve (featips, 2022)

The yield point shows the point at which a material reaches its elastic limit, meaning therefore that once this point has been reached, the material will be permanently deformed. On a stress-strain curve the yield point is often characterized by the presence of a slight hump in the curve (labelled in Figure 9), clearly showing where the material is transitioning into plastic deformation. Based on that data seen in Figure 8, we can estimate the yield strength of the sample to be $\approx 102\text{MPa}$.

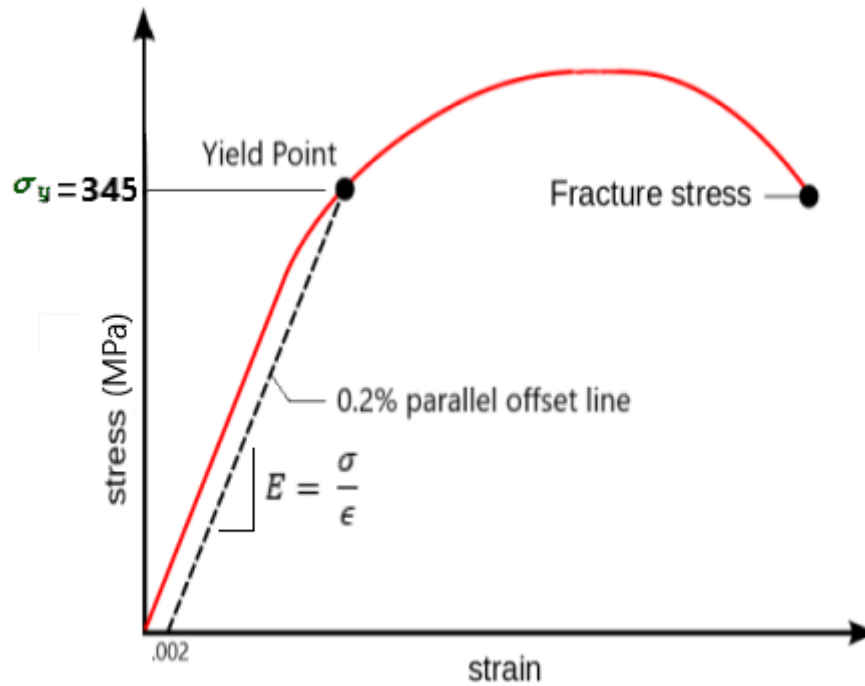


Figure 9- Stress-Strain Curve with .2% Offset (study.com, n.d.)

As discussed by Cahoon, Broughton and Kutzak (1971), a more reliable method of obtaining a yield strength value would be to use the 0.2% offset method. This process compensates for irregularity in the material and small errors in strain calculations. Figure 10 shows what a realistic offset line should look like. The labelled intersect would be taken as a reading for yield point.

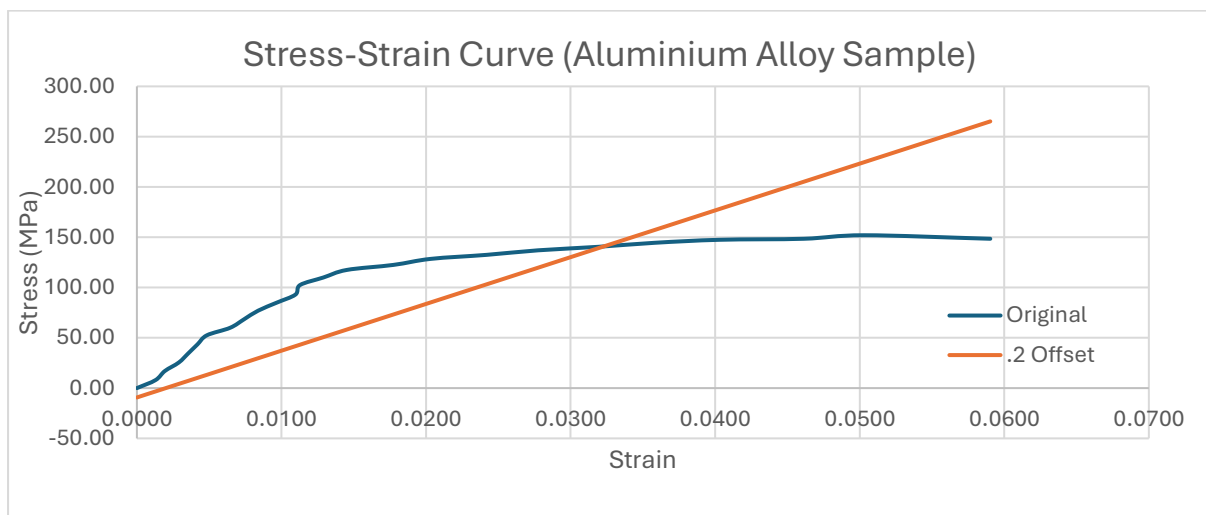


Figure 10- Stress-Strain Curve With 0.2% Offset

Using the obtained data, the offset method does not appear to be. As can be seen in Figure 11, the intersect occurs far into the plastic region and therefore cannot be considered as a realistic yield point value. Therefore, we can consider the original estimate of 102MPa to be more accurate.

The ultimate tensile strength of a material is the absolute maximum amount of stress a material can withstand before fracture. This includes readings within the plastic region prior to necking (local thinning of material prior to fracture). This value can be calculated simply by identifying the highest value on the y-axis (stress) of the graph. Using the excel max function on the range of stress data we can take this to be 152MPa.

Young's modulus is a value that indicates the overall stiffness of a material (resistance to elastic deformation). This value can simply be obtained by taking the gradient of the elastic region on the stress-strain curve. Using excel this can be done simply either by using the slope function or plotting the appropriate range of data onto a graph and applying a trendline with equation.

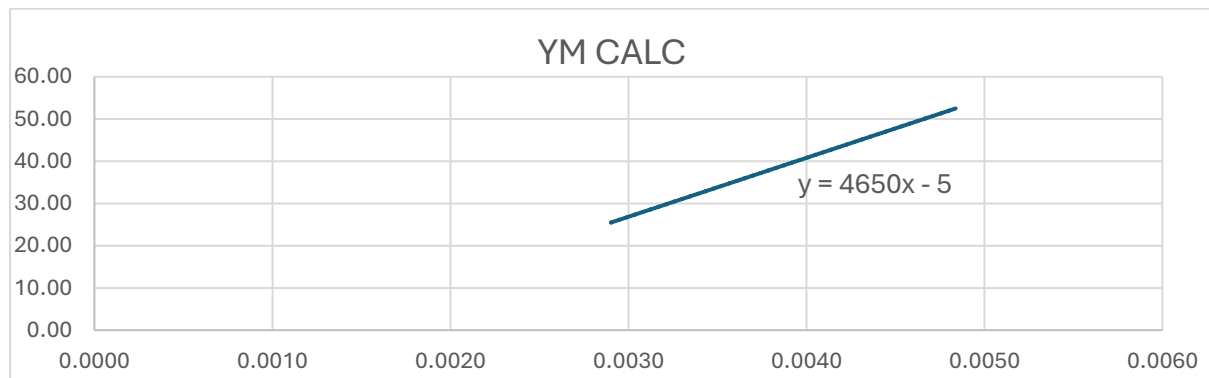


Figure 11- Graph to Calculate Young's Modulus

Figure 12 shows the graph used to calculate Young's Modulus for the sample. It uses data from the most linear section of the elastic region from Figure 6. The gradient of this graph is 4650, therefore giving a Young's Modulus of 4650MPa or 4.65GPa.

6 Conclusion

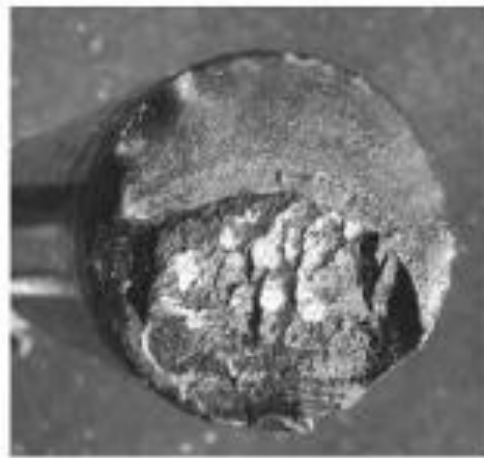


Figure 12- Failure of Aluminium Shaft (UWTSD, 2026)

To conclude, it is to be believed that the driveshaft in question has failed due to a fatigue fracture. Despite the ductility of Aluminium, this does not appear to be a ductile fracture.

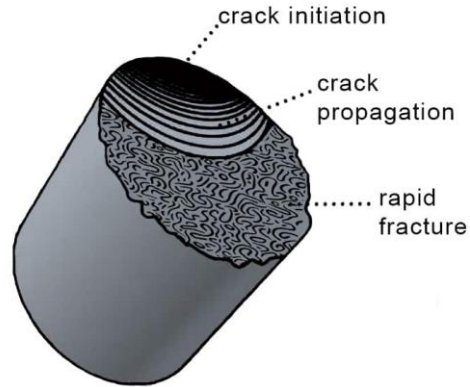


Figure 13- Ductile vs Brittle Fracture (Engineering Stack Exchange, 2021)

The image supplied (Figure 12) lacks the textbook cup-and-cone shape found in a ductile fracture. This is a simple way of seeing that this was not the point of failure. Instead, the image is consistent with a fatigue fracture.

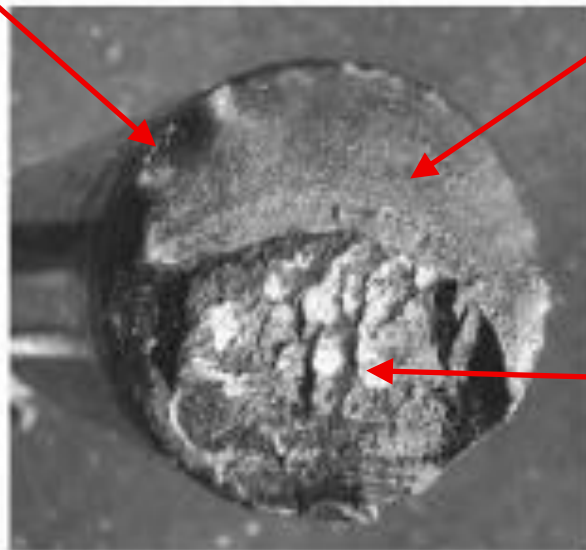
Fatigue Fracture

a visual perspective



Crack initiation

Figure 14- Fatigue Fracture Diagram (The Armoloy Corporation, 2024)



Crack propagation

Rapid fracture

Figure 15- Labelled Failure of Aluminium Shaft (Adapted from UWTSD, 2026)

As can be seen when studying figures 14 and 15, the image provided clearly displays the expected features of a fatigue fracture. Due to the circular nature of the component and the expected forces the driveshaft is expected to receive, we can further classify this fracture as being a 'no stress raiser rotational bend fatigue fracture'.

If we are to trust in the data presented in section 4 (despite the large inaccuracies due to lack of an extensometer in testing) then the 90MPa stress that the part was subjected to is remarkably close to its suspected yield strength of 102MPa. This is an unacceptably low fatigue safety margin. Due to the unforgiving nature of the Dakar Rally, it can be assumed that the part was subjected to stresses of this magnitude a great number of times, thereby exceeding the fatigue strength of the material (maximum stress for loading cycles).

If the previous iteration of the part was able to withstand such forces, then it can be assumed that the new supplier has not treated the new alloy in the same way the old material was. For example, a soft temper or a poor heat treatment cycle (or lack of both) will result in weakness of the alloy. This is due to larger grains which are more likely to cause fracture and reduce stiffness as well as a generally softer material which is more likely to succumb to cyclic stress. As the alloy is unknown, it is also possible that it has been bonded with a higher percentage of soft metal such as copper which again, would not be ideal for a part which needs to be tough and strong.

To prevent a similar issue from arising in the future, it would be wise to conduct a fatigue test with a new proposed material choice. The dynamic conditions seen in a test of this nature will replicate the harsh environment of the rally. If this were to be coupled with detailed Finite Element Analysis (FEA) simulations, then a team would be able to deploy a new material choice with confidence that it will be able to withstand the specific needs of the part and its environment.

Perhaps most importantly, to prevent another failure, the material choice needs to be proven and applicable. A simple way of doing this would be to pick out a known and widely used aluminium alloy such as 7075-T6 which is widely used in aerospace applications due to its durability (ASM, 2001). A material such as this is guaranteed to have a high yield strength and features a good temper which mitigates the risk of

cracking. If durability is of absolute priority, then perhaps a steel replacement could be viable at the cost of additional mass.

It can therefore be concluded that the failure was not due to excessive loading or design flaws, but rather the unsuitable and inconsistent material properties found in the new grade of aluminium alloy. The alloy did not possess appropriate fatigue resistance for its intended application, leading to failure under expected conditions.

7 References

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