

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

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Harry Stark

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Contents

1	Introduction	1
2	Literature Review	2
3	Methodology	4
4	Test Results	6
5	Analysis	8
6	Conclusion.....	8
7	References	10

1 Introduction

The main purpose of this report is to determine if the aluminium used in the failed driveshaft is the primary factor to its failure. This will be achieved through a tensile strength test of a sample with a specimen of the supplied aluminium with a cross-sectional length of 2mm^2 . Through this experiment crucial mechanical properties such as, yield strength, ultimate tensile strength (UTS) and young's modulus can be determined. These results will then be analysed and compared to that of expected values for standard aluminium alloys to assess the suitability of the supplied material.

The outcome of this report will aim to determine the root cause of failure and support its identification whilst making informed recommendations to prevent the same failure from occurring again. This will ensure that the material itself will be able to adhere to the mechanical demands of a rally environment. If the measured properties from the tensile strength test differ from expected values, this could indicate issues such as incorrect alloy selection and inconsistencies in material quality. Understanding these parameters will help the team make informed decisions regarding which material to use and what properties they should be focusing on.

2 Literature Review

The selection of an appropriate material to use for a rally car driveshaft must depend on rigorous testing of mechanical, physical and operational properties under highly dynamic loading conditions. Unlike typical automotive applications, rally environments impose far greater stresses on components. Considerations must be made regarding cyclic stresses, impact loading and exposure to environments that introduce their own unique material focused challenges.

The primary consideration for any material being implemented in a driveshaft's design is torsional strength. The driveshaft is designed to transmit high loads of torque without reaching its maximum available yield strength or reach its point of failure. Torsional loading induces shear stress, which is directly related to the material's shear modulus and yield strength. Materials with high yield strength and shear resistance are essential to prevent permanent deformation under high torque conditions ([Budynas, R.G., Nisbett, J.K. and Shigley, J.E. 2015](#)). Steel alloys, specifically quenched and tempered grades such as AISI 4340, show far greater torsional performance due to its high strength and toughness, making it a benchmark material in drivetrain designs ([Xia, Gavin, and Gavin Xia. 2025](#)).

Fatigue resistance is closely related to strength, which is one of the most important properties to consider in rally applications. Driveshafts are subjected to millions of load cycles under operation, often with different amplitudes due to alternating terrain and traction. Fatigue failure will typically initiate at stress concentration points and come into effect over time, thus leading to sudden fractures. Materials such as steel alloys, have high endurance limits are preferred in cyclic loading applications ([Görzen, David, et al. 2022](#)). In contrast, aluminium alloys exhibit no true fatigue limit, which means that failure can occur at low stress levels given sufficient cycles. This significantly limits their suitability in environments with high cycle and stress applications such as rallying.

Another critical property is toughness, particularly toughness regarding impact. Which defines a materials ability to absorb energy through fracturing. Conditions that vehicles are subjected to during a rally race involve shock loads from different jump heights, sudden increase in torque and contact with uneven terrain. Materials with a low toughness have a higher chance of failing under these conditions. Regarding steel alloys, they have shown more ductile traits and have a high absorption capacity, allowing for plastic deformation before fracturing. On the other end of the spectrum, Carbon fibre reinforced polymers (CFRP) show more brittle failure traits, with no warning before the material fails during use([Zhao, Cong, et al. ,2023](#)). While (CFRP) offers high strength, its low impact resistance is a concern in a high impact environment.

An integral aspect of choosing a material should also be based on its density and its effect on rotational inertia. As lower density materials reduce the mass moment of inertia, improving drivetrain responsiveness and reducing parasitic losses. This is more pronounced in motorsport, where acceleration and throttle response is crucial. Carbon fibre composites and aluminium alloys provide great weight savings compared to steel. However, any benefit of reduced density must be balanced with potential reductions in durability and strength, especially under loads creating stress Kaw ([Xin, Hao, et al ,2025](#)).

A driveshaft with insufficient stiffness may experience excessive twisting, leading to inefficiencies and potential instability. Stiffness, which is represented by the modulus of elasticity (Young's Modulus), influences the amount of elastic deformation under load. Steel has a high modulus of elasticity (200 GPa), thus providing excellent torsional rigidity. Aluminium, has a modulus of approximately 70 GPa, making it less stiff. This downside is potentially remedied by having larger diameters to achieve equivalent performance ([Doty, H.W, et al. ,2025](#)).

Aluminium can have a protective layer of aluminium oxide, which forms when exposed to oxygen in the atmosphere. The thickness of this layer can be increased by an electrochemical process called anodization. This extra layer of protection makes aluminium far less corrosive. Applying this process to a rally environment would see an increase in longevity due to its corrosive resistant properties. However, the aluminium itself will still be vulnerable to debris and impacts, making the material still susceptible to this form of wear ([Kosaba, Takumi, et al.,2023](#)).

Due to potential materials being used in a rally environment, it is ideal that they undergo specific testing based on mechanical stress combined with environmental loading conditions. A typical testing solution to start with would be torsional testing. This makes sense as a driveshaft is expected to handle torque transmission ([Hurd, N.J. ,1996](#)).

3 Methodology

The tensile strength test was carried out on a specimen of the aluminium used in the driveshaft by the rally team. This was done to determine its mechanical properties and assess its point of failure at fracture. The specimen had a cross-sectional length of 2mm^2 and was placed in between the top chuck and the bottom chuck as seen in figure 1. The specimen dimensions were measured with using a calliper to confirm the cross-sectional area and record the original length.

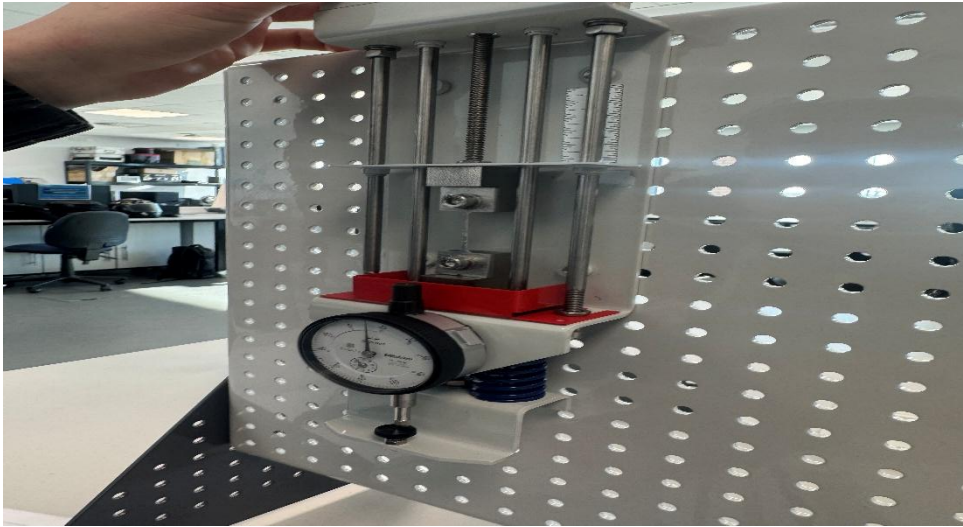


Figure 1 – Tensile testing equipment with specimen in use

The apparatus shown in figure 1 consists of two chucks which grip the specimen and hold it in alignment. It also has a load nut with a scale to measure how many turns are being made during the test. A vertical scale is also incorporated to assess the movement of the specimen as well as a dial indicator to measure the deflection of the internal springs in the machine. As the springs obey Hooke's law, their deflection is proportional to the applied force. This is how the apparatus determines the amount of load. A tensile load was applied gradually in increments of 0.2mm . This was done to ensure a consistent loading rate was applied throughout the test. This process was carried out until the specimen elongated to the point of fracture, as seen in figure 2 and 3.



Figure 2 – Tensile testing – Specimen reaches Fracture by elongation

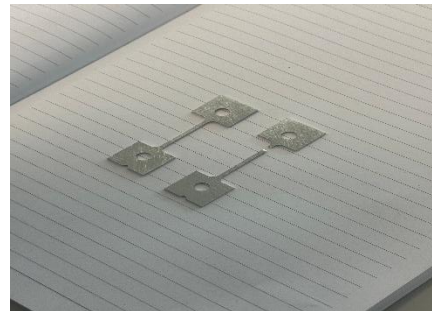


Figure 3 – Tensile testing – Fractured Specimen compared to Specimen before testing

The extension of the specimen was measured by subtracting the dial indicator reading from the total movements of the load nut. The dial indicator reading was also used to determine the applied force (N). The force applied to the specimen is directly proportional to the springs deflection as the springs follow Hooke's Law, these springs can be seen in Figure 4. Subsequently, the force (N) was calculated by multiplying the dial indicator reading by 100.

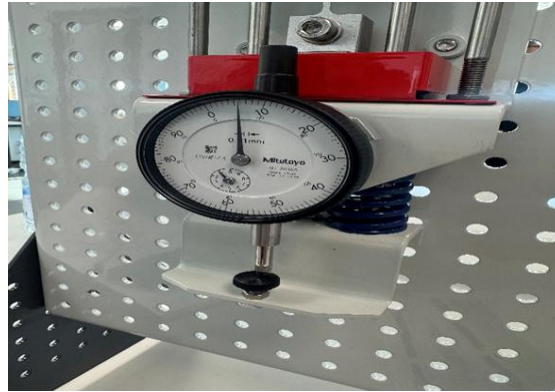


Figure 4 – Tensile testing – Dial - Springs

The recorded values of force (N) and extension were then used to calculate stress (σ) and nominal strain (ϵ). Stress (σ) was found by the force by the cross-sectional area before the specimen fractured. Nominal strain (ϵ) was found by dividing the extension by the original gauge length of the specimen.

A Stress and Strain curve was plotted using the calculated values from the Excel sheet. Yield strength was determined from the graph, and the ultimate tensile strength was identified as the highest amount of stress from the graph. Youngs modulus was calculated from the gradient which was found by determining the linear elastic region. These results will be used for the analysis.

$$\epsilon = \frac{\Delta L}{l}$$

Equation 3-1 - Strain

$$\sigma = \frac{F}{A}$$

Equation 3-2 - Stress

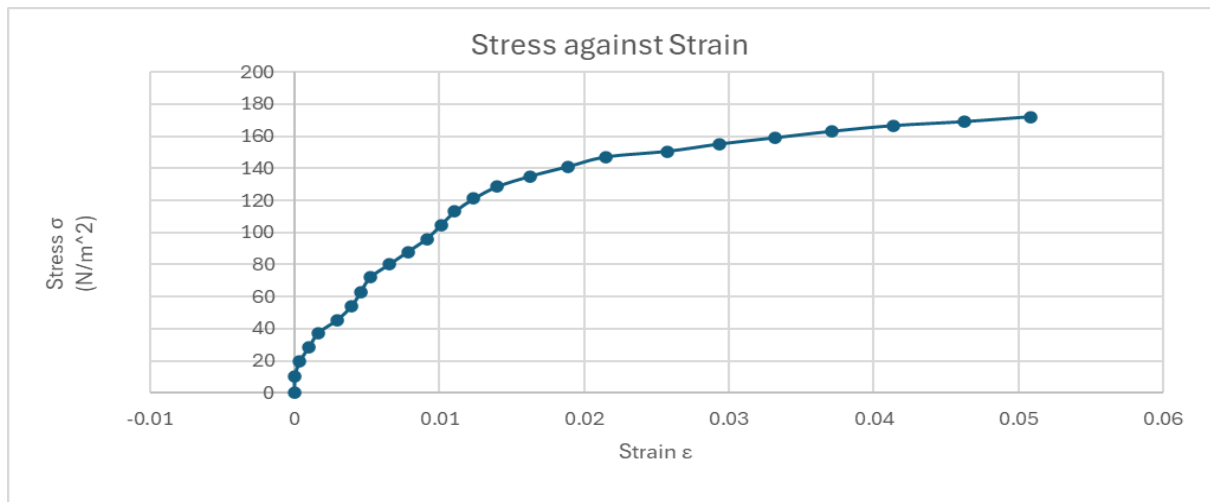
4 Test Results

Specimen Material:	Aluminium
Original Cross-sectional Area: (mm ² or m ²)	2mm ²
Original Length (mm):	30.7
Final Length (mm)	32.26
Ultimate Tensile Strength (N/m ²):	172
Yield Strength (N/m ²):	100
% Elongation:	5.08%
Young's Modulus (GPa)	18.6

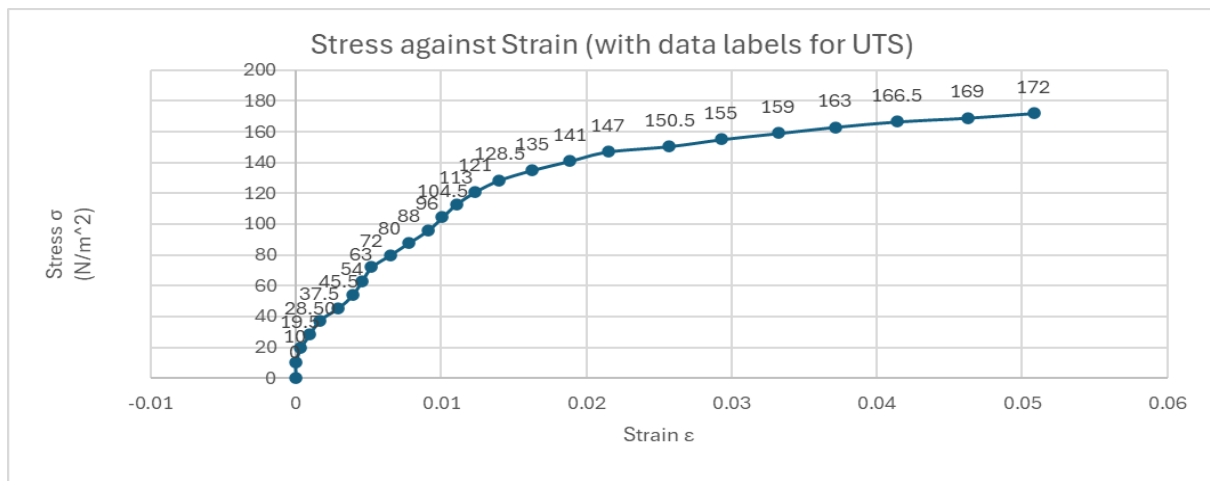
Table 4-1 – Tensile Testing Data - Specimen

Load Nut movement (mm)	Dial Indicator (mm)	Force (N)	Extension (mm)	Stress σ N/m ²	Nominal Strain ϵ
0	0	0	0	0	0
0.2	0.2	20	0	10	0.00000
0.4	0.39	39	0.01	19.5	0.00033
0.6	0.57	57	0.03	28.50	0.00098
0.8	0.75	75	0.05	37.5	0.00163
1	0.91	91	0.09	45.5	0.00293
1.2	1.08	108	0.12	54	0.00391
1.4	1.26	126	0.14	63	0.00456
1.6	1.44	144	0.16	72	0.00521
1.8	1.6	160	0.2	80	0.00651
2	1.76	176	0.24	88	0.00782
2.2	1.92	192	0.28	96	0.00912
2.4	2.09	209	0.31	104.5	0.01010
2.6	2.26	226	0.34	113	0.01107
2.8	2.42	242	0.38	121	0.01238
3	2.57	257	0.43	128.5	0.01401
3.2	2.7	270	0.5	135	0.01629
3.4	2.82	282	0.58	141	0.01889
3.6	2.94	294	0.66	147	0.02150
3.8	3.01	301	0.79	150.5	0.02573
4	3.1	310	0.9	155	0.02932
4.2	3.18	318	1.02	159	0.03322
4.4	3.26	326	1.14	163	0.03713
4.6	3.33	333	1.27	166.5	0.04137
4.8	3.38	338	1.42	169	0.04625
5	3.44	344	1.56	172	0.05081
6					
7					
8					
9					
10					
20					
30					
40					
50					
60					

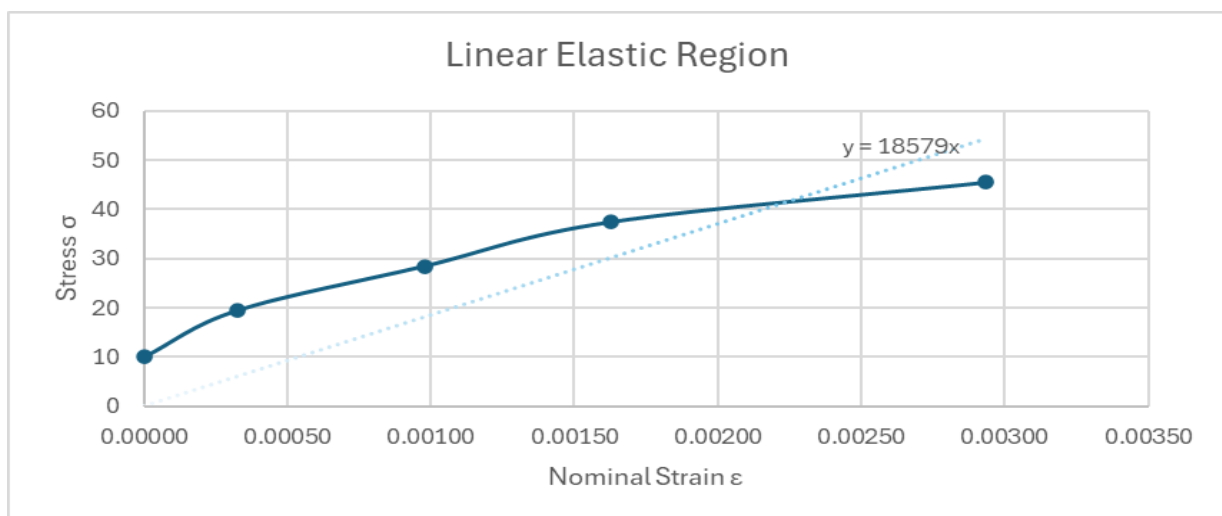
Table 4-2 – Tensile Testing Data – Raw data with Calculated data



Graph 4-1 – Tensile Testing Data – Stress/Strain



Graph 4-2 – Tensile Testing Data – Stress/Strain with data labels for UTS



Graph 4-3 – Tensile Testing Data – Young's Modulus

5 Analysis

The Stress/Strain graphs were used to obtain the main mechanical properties of the aluminium specimen. These properties are ultimate tensile strength (UTS), yield strength and Young's modulus.

From graph 4-1, it can be determined that the yield strength is approximately 100 MPa. The yield strength is where the aluminium specimen stops behaving elastically and starts to permanently deform.

The UTS is the highest amount of stress the aluminium specimen reaches before it starts to fail, which is approximately 172 MPa. This data point can be seen in graph 4-2 and is always the highest point of the graph. In this instance the specimen fractured, meaning there is no more available data.

Young's modulus was found by taking the linear elastic region of graph 4-1 and applying a gradient from 0,0, which can be seen in graph 4-3. This data is indicative of the specimen's stiffness. The value obtained was approximately 18.6 GPa.

Comparatively, the typical Young's modulus for a standard aluminium alloy is around 69-71 GPa. Given the result of 18.6 GPa for the specimen's Young's modulus, it is obvious that the calculated value from graph 4-3 is significantly lower than that of the expected value of a standard aluminium alloy.

6 Conclusion

Yield strength and UTS can vary depending on the alloy and heat treatment, as the driveshaft was tested with a 90 MPa, it is unlikely that these properties had any effect on the failure. Unless the rally car was subjected to near constant spikes in excess load, the 100 MPa yield strength would not be the cause of failure.

The potential cause of the driveshafts failure appears to be from the use of low-quality or poorly manufactured aluminium alloy. Given the 18.6 GPa value, it is apparent that this aluminium should not be used in a rally environment. Although the UTS and yield strength are indicative of a material with properties that can withstand stress and strain in this environment, the 18.6 GPa value shows that the aluminium alloy that was used in the driveshaft is significantly less stiff than it should be.

The root cause appears to be from deficient material from either poor alloy selection or improper manufacturing. This means that the tested aluminium will deform more under the same loading conditions as a standard aluminium alloy, this alone constitutes the driveshafts reason for failure.

To ensure the failure does not occur again, it is imperative that material verification procedures should be implemented. This can be done by checking a supplier's certification, which would ensure that quality control has taken place and a compliance of recognised standards for aluminium alloys regarding driveshaft applications. It is also recommended that a tensile strength test be carried out before installation to confirm mechanical properties ([Raval, Dr Bhargav, 2024](#)).

Based on the results and requirements for application, it is recommended that anodised 6061-T6 aluminium alloy be used for the driveshaft. This will allow the new material to be corrosive resistant, which is more suitable for a rally environment. 6061-T6 typically has a yield strength of 276 MPa and a UTS of 310 MPa with a Young's modulus of 68.9 GPa. This guarantees a significant improvement

regarding strength and stiffness compared to the tested aluminium as well as ensuring a better margin of safety from deformation when considering the high load environment of the driveshaft application ([ASM Aerospace ,2024](#)).

Although 6061-T is a good choice for the driveshaft, it does not possess a known fatigue limit, so the chance of failure is still present even if it's almost negligible by comparison. It can be noted that steel 4340 would be the safest option as it possesses a yield strength of 470 –1,270 MPa, (this value varies with thickness) and a UTS of approximately 1,355 MPa. These properties prove steel 4340 to be a favourable choice for the driveshaft ([Yao, Ju, et al. ,2024](#)). However, a downside to consider would be that the density of steel 4340 (7.85 g/cm^3), is greater than that of aluminium 6061-T6 (2.7 g/cm^3). This would increase rotational inertia, contributing to parasitic drain and overall vehicle mass. Therefore, it may not be the most optimal choice when accounting for performance.

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