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Engineering Materials

Materials and Manufacturing

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2500220

Motorsport Engineering

Submission Date: 27/4/26

Module Code: ACHA4025

Word count: 1934

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Chapter 1 – Introduction

The performance demands of the Dakar Rally place exceptional mechanical and environmental stresses on every component of a racing vehicle, particularly those within the drivetrain. During the fourth and fifth stages of the event, both team vehicles suffered complete drive shaft fractures, resulting in immediate loss of mobility and early retirement from the competition. The failures occurred despite the shafts being manufactured and assembled using the same design, processes, and specifications as previous successful iterations. This unexpected failure has led to a detailed engineering investigation to determine the underlying cause of the fractures and to identify measures that will prevent recurrence in future events.

To support this investigation, a representative sample of the aluminium alloy used in the drive shafts has been provided for mechanical testing. Since the exact alloy grade is unconfirmed, a tensile test will be conducted to establish the material's fundamental mechanical properties, including yield strength, ultimate tensile strength (UTS), and Young's modulus. These values are critical for assessing whether the material meets the performance requirements expected for a component subjected to high cyclic loading in an off-road racing environment. The tensile test will also allow comparison between the measured properties and typical values for aluminium alloys commonly used in drivetrain applications. Any deviation from expected behaviour including reduced strength, lower stiffness, or early plastic deformation could highlight issues related to material quality, supplier variation, or improper processing.

The maximum operational stress recorded on the component was 90 MPa, a value that must be interpreted in the context of the tensile test results. If the measured yield strength is only marginally higher than this operational stress, the component may have been functioning with an insufficient factor of safety. In the extreme loading environment of the Dakar Rally, which is known for its rough terrain, which puts the vehicles through repeated impacts and vibration, such a narrow margin of error could lead to accelerating fatigue crack initiation and propagation, particularly if any surface imperfections or stress concentrations were present.

This report aims to evaluate the material through tensile testing, analyse the resulting stress-strain graph, and interpret the findings in the context of the observed failure. By combining mechanical test results with fracture surface evidence and operational loading data, the investigation will look for a cause of the shaft failures and will propose practical engineering solutions. Such as material selection, heat treatment options, and design or manufacturing improvements, to enhance the durability and reliability of future drive shafts used in this demanding motorsport environment.

Chapter 2 – Literature Review

The drive shaft of a car performing in Dakar, a high-performance off-road vehicle must be able to withstand many possible loading conditions including, torsion, bending and cyclic fatigue. Therefore, the materials selected for this application must be of a high yield strength, this is the point that beyond which any further load will cause permanent deformation (Sharma, 2024), this is a critical point in the stress-strain graph for this application. The material must also be tough to withstand impact loading, toughness is the materials ability to absorb energy and plastically deform without breaking this allows for good shock absorption (Engineering Technology, 2026). The material chosen must have high fatigue resistance as the drive shaft will go through repeated loading. The ultimate tensile strength of the material is also important, this is the maximum stress that a material can withstand without breaking (Keane and McClements, 2025), this value is critical to know that the drive shaft will still perform under the peak load.

Other factors when choosing a material must also be considered, such as machineability, weight and cost. From the listed properties above, an aluminium alloy seems like a sensible material to choose for this application, due to its strength to weight ratio (European Aluminium, 2011). Given the unknowns about the newly manufactured drive shaft aluminium alloy, it is important to test a specimen of the material so that the critical values are known of the materials properties, this includes the ultimate tensile strength, yield strength and the Youngs modulus for the material. To find these values, a tensile test must be taken of the material. A tensile test applies a load to the specimen's axis until the material breaks, from which stress and strain can be calculated allowing for a stress-strain graph to be plotted (Singh, 2012). This graph will then allow for these critical values of material properties to be calculated from it.

Chapter 3 – Methodology

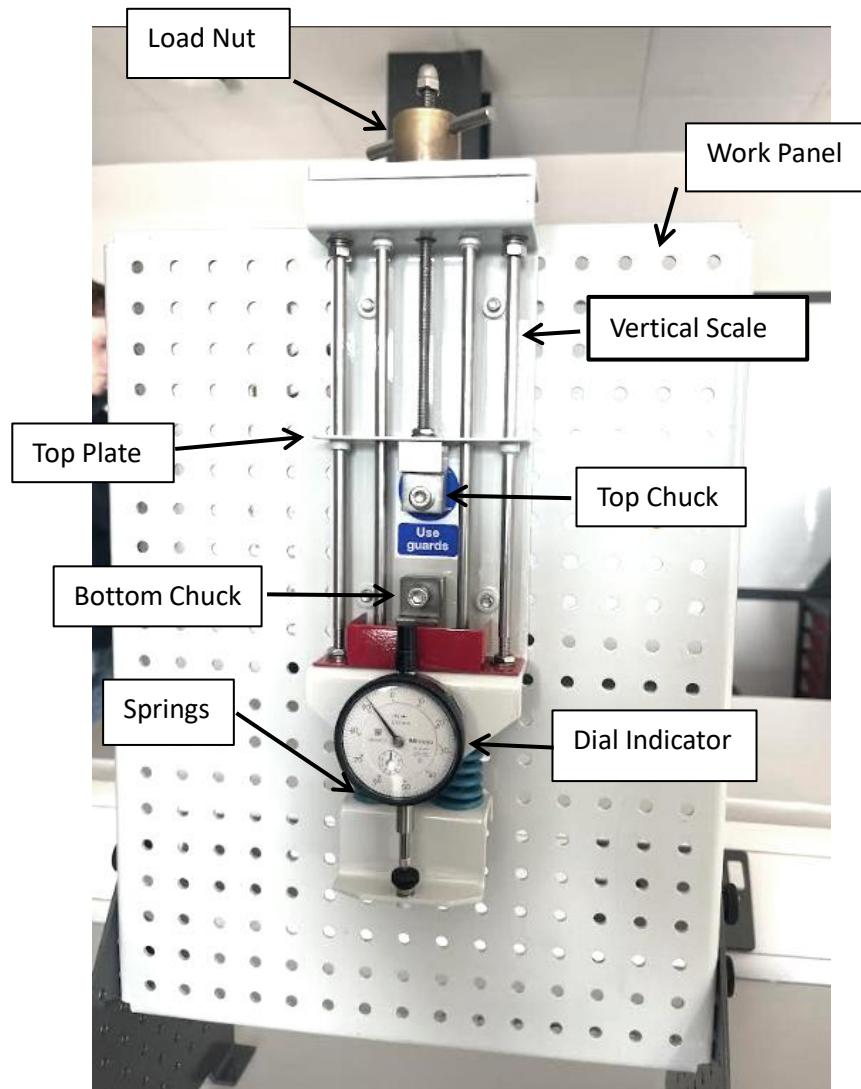


Figure 1 Tensile Tester Components



Figure 2 Aluminium Specimen

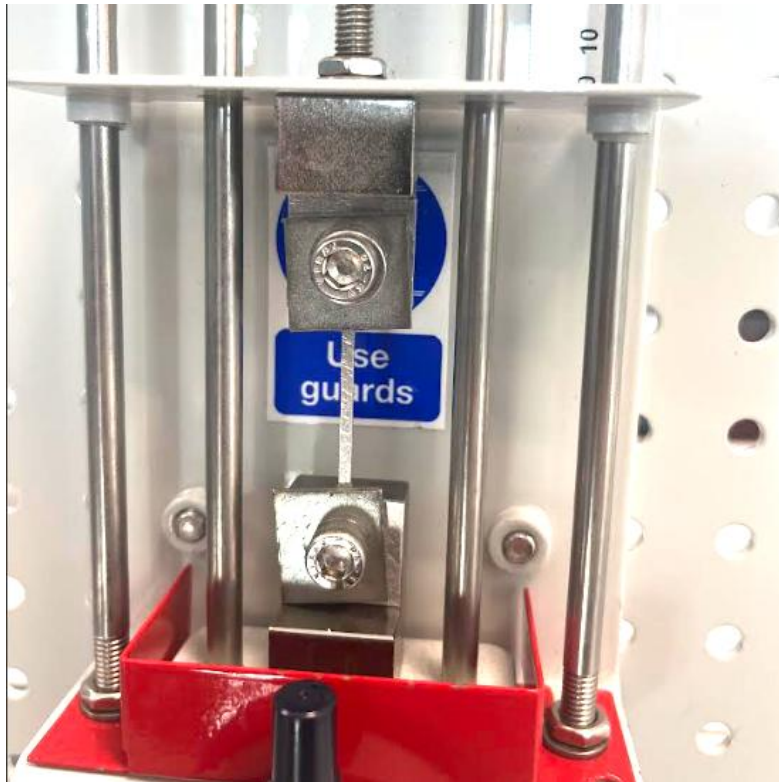


Figure 3 Aluminium Specimen in Chucks



Figure 4 Dial Gauge Zeroed

To begin the aluminium specimen was placed in the chucks, which were then tightened using an Allen key. The dial indicator was then set to zero, this was done by adjusting load nut until the specimen had just begun to move, at that point the dial indicators outer case was turned until it was pointing at zero.

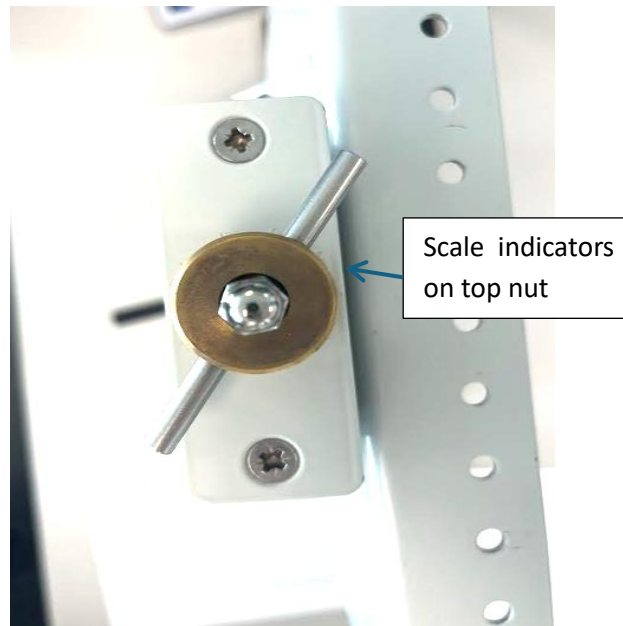


Figure 5 Top Nut Scale



Figure 6 Reading on Dial Indicator During Experiment

The top nut was then turned by two markers, an equivalent value of 0.2mm, at which point the reading of the dial indicator was taken and recorded. This was repeated until the specimen broke.



Figure 7 Specimen Broken in Chucks



Figure 8 Comparison of Broken and New Specimen

Chapter 4 - Results

Table 1 Aluminium Results

cross section area (mm²)	2		Width (mm)	2	
original length (mm)	30.12		Height (mm)	1	
load nut movement	Dial indicator	Force	Extension	Stress σ	Nominal Strain ϵ
(mm)	(mm)	(N)	(mm)	(N/m²)	(No Units)
0	0	0	0	0	0.00000
0.2	0.16	16	0.04	8000000	0.00133
0.4	0.34	34	0.06	17000000	0.00199
0.6	0.53	53	0.07	26500000	0.00232
0.8	0.71	71	0.09	35500000	0.00299
1	0.88	88	0.12	44000000	0.00398
1.2	1.05	105	0.15	52500000	0.00498
1.4	1.23	123	0.17	61500000	0.00564
1.6	1.41	141	0.19	70500000	0.00631
1.8	1.6	160	0.2	80000000	0.00664
2	1.76	176	0.24	88000000	0.00797
2.2	1.92	192	0.28	96000000	0.00930
2.4	2.1	210	0.3	1.05E+08	0.00996
2.6	2.25	225	0.35	1.13E+08	0.01162
2.8	2.36	236	0.44	1.18E+08	0.01461
3	2.48	248	0.52	1.24E+08	0.01726
3.2	2.54	254	0.66	1.27E+08	0.02191
3.4	2.65	265	0.75	1.33E+08	0.02490
3.6	2.75	275	0.85	1.38E+08	0.02822
3.8	2.81	281	0.99	1.41E+08	0.03287
4	2.86	286	1.14	1.43E+08	0.03785
4.2	2.92	292	1.28	1.46E+08	0.04250
4.4	2.96	296	1.44	1.48E+08	0.04781
4.6	2.98	298	1.62	1.49E+08	0.05378
4.8	failed	failed	failed	failed	failed

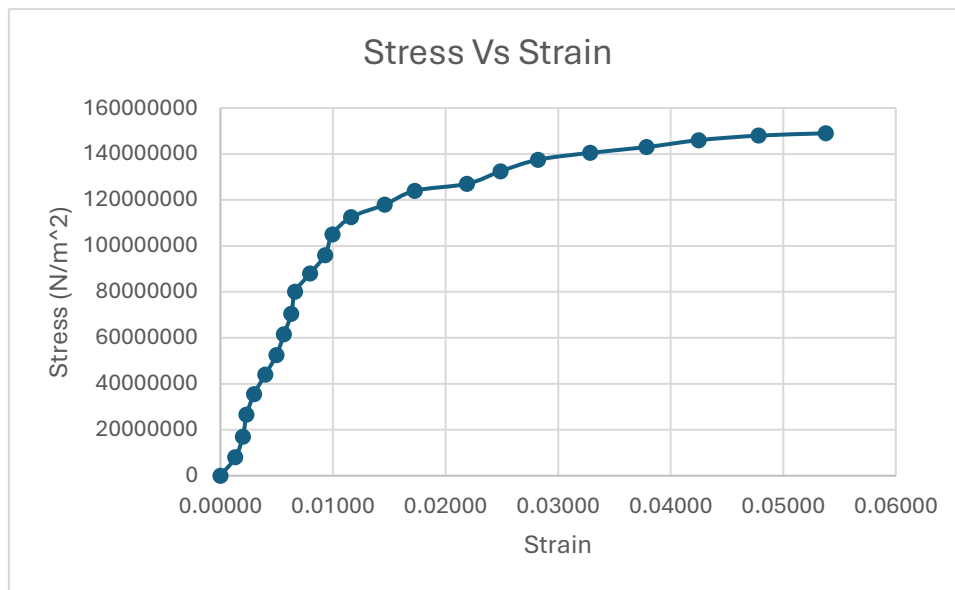


Figure 9 Stress Vs Strain Graph

Chapter 5 – Analysis

Graphical Calculation of Youngs Modulus:

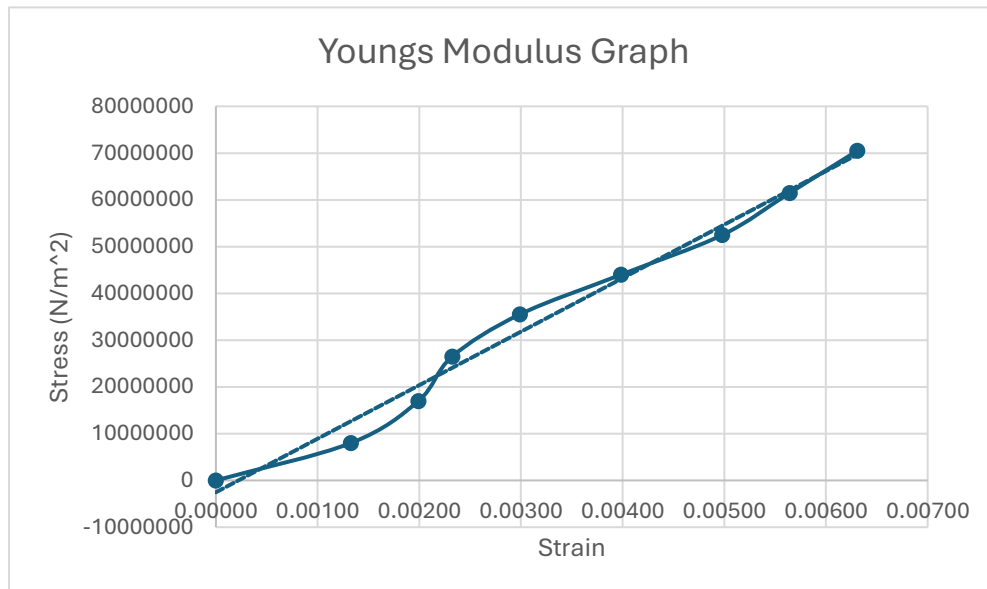


Figure 10 Elastic Region of Stress Vs Strain Graph

Calculation of Youngs Modulus:

$$E = \frac{\Delta \sigma}{\Delta \epsilon}$$

$$E = \frac{70500000 - 8000000}{0.00631 - 0.00133}$$

$$E = 12.55 \text{ GPa}$$

Ultimate Tensile Strength:

This is the maximum stress the specimen can withstand without necking or fracture. In this case the value is the last before failure occurred at a value of 149 MPa.

Calculation of Yield Strength:

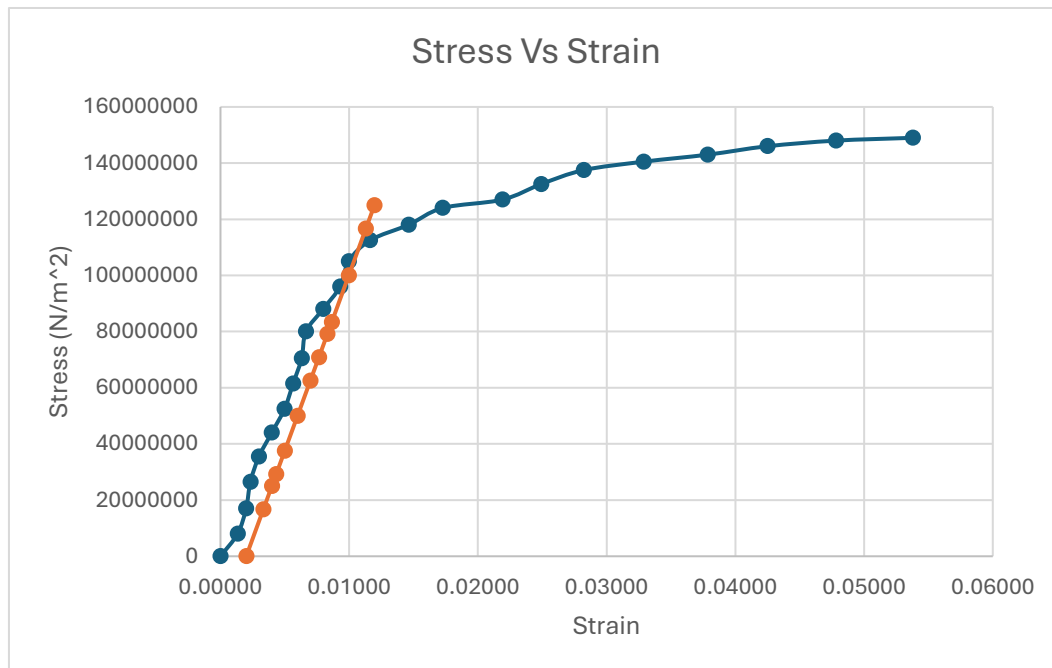


Figure 11 0.2% Offset Graph to calculate Yield Strength

Table 2 0.2% Strain Calculations

0.2 strain (No Units)	Gradient Multiplier (No Units)
2.00E-03	0.00E+00
3.33E-03	1.67E+07
3.99E-03	2.50E+07
4.32E-03	2.92E+07
4.99E-03	3.75E+07
5.98E-03	5.00E+07
6.98E-03	6.25E+07
7.64E-03	7.08E+07
8.31E-03	7.92E+07
8.64E-03	8.33E+07

Using the 0.2% offset, new strain values were calculated and plotted against a strain multiplied by the Young's modulus to ensure the line was parallel to the elastic region of the graph, where the two lines intersected was the Yield strength.

$$\therefore \sigma_y = 117 \text{ MPa}$$

The above results from the tensile test range in accuracy, while UTS of 149 MPa and yield strength of 117 MPa are similar to typical values of around 70-300 MPa and 100-250 MPa, respectively (Zhang, 2024 and Civils Guide, 2023). The Youngs modulus value is significantly smaller than the expected value of around 70 GPa (The Engineering ToolBox, 2003).

The value of Youngs Modulus being low could be attributed to a number of factors, experimental error being a probable cause. Error could include initial slack in the setup, the fact the specimen was also small at 30.12mm meaning any inaccuracies were increasingly sensitive to the overall extension. The extension was measured using a dial gauge attached to springs, measuring displacement, therefore deformation of the testing equipment could also have impacted the reliability in the results (Womack, 2023).

The extension being too large then led to the increased strain value, which when plotted provided an underestimation of Youngs modulus. The yield strength could also have been mildly impacted from this due to the Youngs modulus being used to create a parallel gradient for the 0.2% offset line. However, there should be no adverse effect in the calculation of UTS due to it relating to force and original cross-sectional area.

Chapter 6 – Conclusion

The image of the drive shaft shows the fractured surface, with two distinct regions. This suggests a failure that happened due to fatigue followed by a final overloaded force through the material. The sample shows a smooth surface across most of the surface area, showing signs of the crack propagating under cyclic loading (Doreau-Malioche *et Al.* 2018). The other section of the drive shaft fracture has a rough, highly textured break, associated with sudden brittle overload, this suggests a sudden failure once the cracked surface could no longer support the load (Sengupta, no date). Sengupta also discusses how the original crack is likely to have occurred due to a high concentration of stress at that point. The surface of the material may have had an imperfection or a machining mark.

Although the drive shafts were manufactured and assembled identically as the previous iteration, the recent change in supplier of material could lead to variation in quality and processing of the material which could have led to the change in fatigue performance. Therefore, to prevent similar failures it is important to look at the critical properties of the material and investigate what improvements could be implemented in manufacturing.

From the tensile test results, the ultimate tensile strength (149 MPa) and yield strength (117 MPa) fall within the expected range for aluminium alloys, although they are towards the lower end. However, the maximum stress experienced during the vehicle's performance was 90 MPa, which is a large proportion of the measured yield strength. This suggests that the component was operating with a relatively small safety margin with a factor of safety of 1.3, this is particularly small given that the part will go through extreme cyclic loading conditions. In an environment such as the Dakar Rally, where components are subjected to repeated dynamic loads, this would accelerate fatigue crack initiation and growth, especially at the later stages in the rally. It is therefore important, to consider possible solutions to improve the material for this application.

There are many possible solutions to this, including heat treatments for the aluminium alloy, and choosing the best alloy for the application. For example, the use of Aluminium 6061- T6 would be a practical choice for this application (World Material, 2026), the alloy is tempered allowing for a higher UTS and yield strength while not losing any of the favourable properties of the aluminium alloy previously used. Although a change in material heat treatments is not the only way to improve the drive shaft, reducing stress concentrations is critical to this piece as this was where the crack likely first began. Surface treatments like shot peening could have been used to improve the fatigue life (Wang, P *et Al.*, 2026).

In summation, the failure was caused by fatigue initiated at a surface stress concentration under cyclic loading, followed by final overload. The combination of high operational stress relative to material strength and potential variation in material properties contributed to the failure. However, potential mitigations can be put in place to prevent the issue arising again.

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