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Engineering Materials (ACHA4025)

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1. Introduction

During competitive motorsports, failure of important components can have significant performance or safety implications. During the fourth and fifth stages of the Dakar Rally, two vehicles from the same team experienced drive shaft fractures which caused early retirement for both vehicles. The manufacturing process for these components were proven reliable in the design and production department which implies the failure was not due to any design changes. However, the team has recently changed their material supplier for their aluminium which is used in their aluminium alloy. Due to the recent change in supplier, the grade and temper of the material is currently unconfirmed. Due to this, it is believed that the failure is a material issue. This assignment aims to determine the characteristics of the material through a tensile test and calculating the yield strength, ultimate tensile strength and young's modulus. By analysing these results, the cause of the failure can be hypothesised, and potential fixes can be proposed to avoid similar failures further on in the Dakar Rally.

2. Literature Review

2.1. Strength

Strength is one of the most critical mechanical properties when selecting materials for high-performance applications such as drive shafts for motorsport vehicles. Strength refers to the ability for a material to withstand an applied load without failure. One of the key concepts for strength in a material is the stress and strain. Stress is the internal resistance of a material to an applied force, while strain is the deformation or elongation that results from stress (Accu (2026)). Another factor of strength is the materials elastic limit. Elastic limit is the maximum stress a material can take before being permanently deformed (Accu (2026)). Lastly, the ultimate strength of a material is the maximum amount of stress the material can take before failure. There are multiple ways to measure the strength of a material, including tensile testing, compression testing, shear testing and stress-strain analysis (IPN (2025)). Tensile testing is where a material is stretched until failure. This provides data on tensile yield strength, ultimate yield strength, ultimate tensile strength and elongation. Compression testing is used to see how a material performs under compressive forces until failure. This provides data for the compressive strength of a material. Shear testing is when materials are tested by sliding against a surface until the material tested shears. This provides data on when a material would reach sliding failure. Lastly, stress-strain analysis provides a view on how a material performs under load by plotting the two forces against each other (IPN (2025)).

2.2. Toughness

Toughness is defined by the ability for a material to absorb energy and plastically deform without fracturing. It is a particularly important in off-road racing such as the Dakar Rally as the vehicle is subjected to frequent impacts. Toughness is a combination of ductility and strength. This means that a material with high toughness can withstand both high stress and significant deformation before breaking (REFERENCE). To calculate toughness, you use the area under the stress-strain curve from doing a material tensile test. This represents the total energy a material is able to absorb before failure (reference).

2.3. Ductility

Ductility is the ability of a material to undergo a significant amount of plastic deformation before fracturing. Unlike brittle materials, ductile materials show signs before breaking instead of suddenly snapping (Protolabs (2025)). This allows ductile materials to be bent into complex shapes without cracking. Two ways to measure ductility are percentage elongation and percentage reduction. Percentage elongation measures how much a material deforms as a percentage of the original length once it is pulled to failure during a tensile test. Percentage reduction measures the narrowest part of a specimen after fracturing during a tensile test (Metal Supermarkets (2018)).

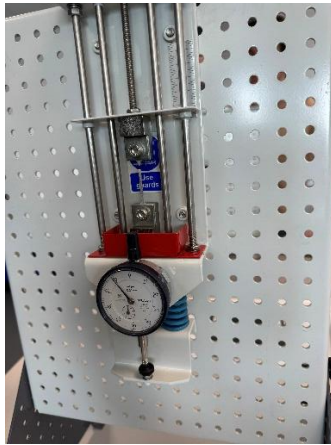
2.4. Fatigue Limit

Fatigue Limit is when a material weakens due to fluctuating loads on the material causing eventual failure. Unlike other properties, the damage builds up slowly before eventually breaking. (Andreas Velling, Factory (2024)). There are multiple ways to calculate fatigue limit, these include the stress-life method, the strain-life method and the crack growth method. The stress-life method is done by

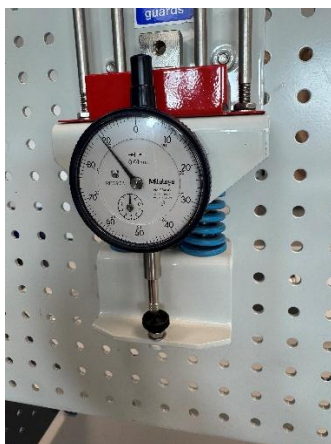
putting the material under different stress amplitudes and plotting a curve from the results. The strain-life method is to plot a graph of strain against life once the strain is no longer elastic. Lastly, the crack growth method measures the amount a crack has grown in a material per stress cycle. You can use the crack growth to estimate how long a material will take to reach failure (Andreas Velling, Factory (2024)).

3. Methodology

The tensile test was carried out using a TecQuipment ES6 Tensile Tester to determine the mechanical properties of the material. Firstly, the tensile tester is securely mounted onto a work panel. The tensile tester applies a tensile load through a load nut mechanism, whilst a dial indicator measures the corresponding deformation of calibrated springs, allowing force to be measured.



(Figure 1: Tensile Tester with fractured specimen)



(Figure 2: Dial Indicator)

Before testing, the width, length and thickness of the specimen are measured using a vernier calliper. These measurements are used to calculate the cross-sectional area and initial length required for stress and strain calculation. The specimen is then mounted between the upper and lower chucks of the tensile tester. A small preload is applied, and the dial indicator is set to zero.



(Figure 3: Vernier Calliper)

The test is performed by gradually applying a tensile load of 0.2mm through incremental turns of the load nut. At each increasing 0.2mm measurement the measurement on the dial indicator is recorded. The turning of the load nut is turned at a consistent speed to ensure reliable data. The test is continued until the specimen fractures. Once the specimen fractures, the results are put into an excel spreadsheet to be analysed and for further calculations to be done.



(Figure 4: Aluminium Alloy specimen before and after fracture)

4. Test Results

Load Nut Movement (mm)	Dial Indicator	Dial Indicator (mm)	Force (N)	Extension (mm)	Stress (N/m ²)	Nominal Strain
0.0	0.0	0.000	0.0	0.000	0.00E+00	0.00000
0.2	16.5	0.165	16.5	0.035	9.17E+06	0.00113
0.4	34.5	0.345	34.5	0.055	1.92E+07	0.00177
0.6	54.0	0.540	54.0	0.060	3.00E+07	0.00194
0.8	71.5	0.715	71.5	0.085	3.97E+07	0.00274
1.0	90.0	0.900	90.0	0.100	5.00E+07	0.00323
1.2	107.5	1.075	107.5	0.125	5.97E+07	0.00403
1.4	126.0	1.260	126.0	0.140	7.00E+07	0.00452
1.6	144.5	1.445	144.5	0.155	8.03E+07	0.00500
1.8	161.5	1.615	161.5	0.185	8.97E+07	0.00597
2.0	179.0	1.790	179.0	0.210	9.94E+07	0.00677
2.2	196.5	1.965	196.5	0.235	1.09E+08	0.00758
2.4	215.0	2.150	215.0	0.250	1.19E+08	0.00806
2.6	227.5	2.275	227.5	0.325	1.26E+08	0.01048
2.8	238.0	2.380	238.0	0.420	1.32E+08	0.01355
3.0	250.0	2.500	250.0	0.500	1.39E+08	0.01613
3.2	257.0	2.570	257.0	0.630	1.43E+08	0.02032
3.4	266.5	2.665	266.5	0.735	1.48E+08	0.02371
3.6	273.5	2.735	273.5	0.865	1.52E+08	0.02790
3.8	278.0	2.780	278.0	1.020	1.54E+08	0.03290
4.0	297.0	2.970	297.0	1.030	1.65E+08	0.03323
4.2	Snapped	N/A	N/A	N/A	N/A	N/A

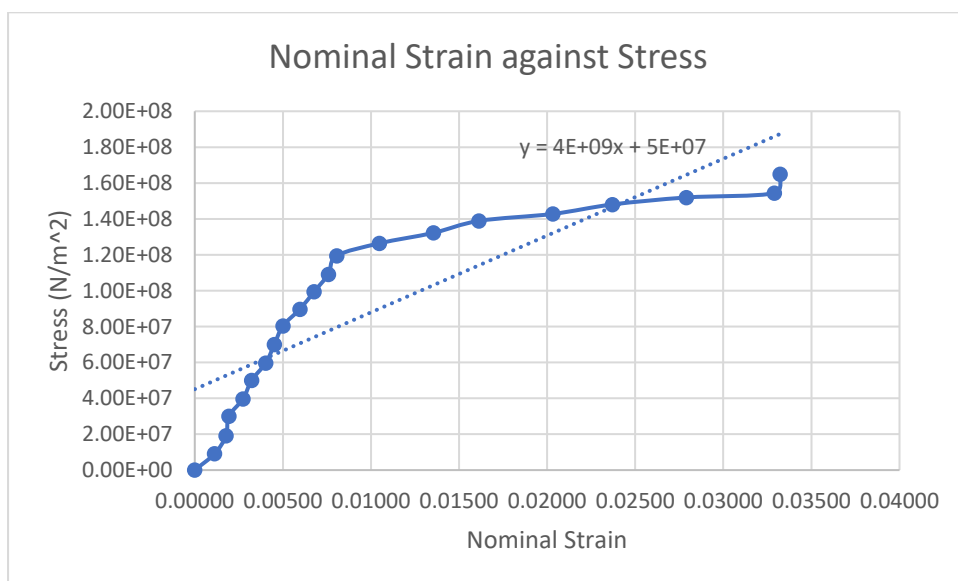
(Figure 5: Results table)

Original Cross-Sectional Area (m ²)	Original Length (mm)
1.80E-06	31

(Figure 6: Specimen measurements)

Tensile Strength (N/m ²)	Yield Stress (N/m ²)	% Elongation
1.65E+08	1.19E+08	3.322580645

(Figure 7: Further equations)



(Figure 8: Graph of Nominal Strain against Stress)

5. Analysis

The tensile test results indicate that the aluminium alloy that was used for the failed drive shafts exhibits a relatively low stiffness and strength compared to what would be expected for high-performance racing components. A typical aluminium driveshaft is made from 7075-T6 alloys (Amy Han, ST Cardan Shaft (2025)) which has a Young's modulus value of around 70GPa (MakeltFrom.com (2020)). The Young's modulus is approximately 17GPa when calculated from the stress strain data which is significantly below typical values of Young's modulus for standard aluminium driveshafts. This suggests that the driveshaft was made using an incorrect alloy, improper temper or material defect, however, with the new aluminium supplier it can be assumed the material was the issue.

The ultimate tensile strength was found to be around 165 MPa with yielding estimated at roughly 110-120 MPa. Given that the maximum operational stress recorded during the Dakar Rally stages was 90MPa, this allows a modest safety margin between normal working conditions and the onset of plastic deformation. However, due to the combined effects of cyclic loading, shock impacts and the harsh terrain of rally racing, the shafts are still likely to be operating close to their elastic limits. This could significantly increase the chance of a fatigue crack or rapid propagation after a particularly harsh landing. This could be another reason for a sudden fracture in the drive shaft.

6. Conclusion

The results indicate that the drive shaft failures during the Dakar Rally were most likely caused due to inadequate material from their new supplier rather than a manufacturing issue on the teams part. The calculations showed that due to the low Young's modulus and average yield strength combined with the extreme nature of the Dakar Rally made the drive shafts highly vulnerable to fatigue and sudden fracture. The unusually low stiffness further suggests that the alloy used was not to expected specification. This reinforces the idea that the material is the issue due to the recent supplier change. It would be recommended for the team to either ensure that their new supplier does better quality control or to find another new supplier. It would also be recommended for the team to do tensile tests on a new aluminium before committing to putting it on the Rally cars to avoid this eventuality in future races.

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