

University of Wales Trinity Saint David

Wales Institute of Science and Art



Prifysgol Cymru

Y Drindod Dewi Sant

University of Wales

Trinity Saint David

Engineering Materials

Materials and Manufacturing (ACHA 4025)

Luke Jacobs

2403849

04 / 2026

Contents

Contents

1. Introduction	1
2. Contextual And or Background Information	2
2.1 Strength Testing	2
2.2 Hardness Testing	3
2.3 Fatigue Strength Testing	4
3. Methodology	5
4. Test Results	7
5. Results analysis	9
5.1 Youngs Modulus	9
5.2 Yield Strength	9
5.3 Ultimate Tensile Strength	10
5.4 Strain	10
5.6 Images of Test Specimen Failure	11
6. Conclusion	12
6.1 Failure modes	12
6.2 Rectification to reduce further failures	13
7. References	14

Figure 1 - Failure of Dakar Driveshaft (Rogers, 2026)	1
Figure 2 - ES6 TecQuipment Tensile testing machine	5
Figure 3 – Load Nut and markings from test rig.	6
Figure 4- A Plot of Stress over Strain for a specimen of Aluminium alloy From Tensile Test	8
Figure 5 - A plot of Force over Extension from Tensile Test	8
Figure 6-Failed test specimen next to original part	11
Figure 7 - Broken specimen with a small amount of Goose-necking	11
Table 1 - Raw (Column 1-2) and Processed (Column 3-6) Data from Tensile Test	7
Table 2 - Sample Dimensions	7
Table 3 - Calculated Values	7
Equation 1 - Brinell Hardness Equation	3
Equation 2 - Youngs Modulus	9
Equation 3 - Yield Point Quantification	9
Equation 4 - Strain Equation	10
Equation 5 - Stress Equation	10

1. Introduction

Durability of materials in racing is one of the most heavily weighted parameters of material selection within competition vehicles regardless of it being a short sprint or as in this case the Dakar Rally, the multi-day several thousand-kilometre desert rally raid race. (Dakar.com, no date)

Currently two cars from the same team have experienced the same driveshaft failure in stages 5 and 6 of the rally, the production methodology of these driveshafts has remained the same however the aluminium supplier has changed, the suspected root is that the material spec is not correct for the conditions as they will need to be able to withstand stresses of up to 90MPa to cope with the forces from the rally as if not these failures could be caused by plastic deformation and fracturing leading to premature failures. (Rogers, 2026)

A sample has been provided to be tested to evaluate the mechanical properties of the alloy used to make the driveshafts, via the means of tensile testing to allowing for values to be calculated and compared to see if the material is suitable for the Dakar application to see if the materials are the root cause of the failures.



Figure 1 - Failure of Dakar Driveshaft (Rogers, 2026)

2. Contextual And or Background Information

All materials have different properties that can be categorised such as mechanical, thermal and electrical, at varying levels, each of these can be broken down into subcategories for example mechanical properties could be Strength, hardness, elasticity, ductility toughness, fatigue strength, just to name a few important examples.

These factors help to develop a property profile for each material, which is useful for comparing suitability of materials for any given component. (Ashby, 2025)

To obtain this property profile the materials need to be tested these properties have a variety of test methods possible all focusing on individual parameters to help evaluate and assign a value or ranking of the properties between materials, in the case of the driveshafts it is only really mechanical and possibly a small amount of thermal that are the only real areas of interest for this project, as for overcoming the issue machineability may need to be assessed as the ideal material may not be feasible to machine.

2.1 Strength Testing

Mechanical strength is generally composed of three subcategories; tensile, compressive and shear.

Tensile or ultimate strength is the maximum stress a material can withstand while being pulled in opposing directions, for most metals and some composites this is greater than the yield strength usually due to work hardening or loading the reinforcements respectfully. (Ashby, 2025)

Compressive strength which is the opposite work of tensile which is the maximum force a material can take being compressed before deforming.

Shear strength is the maximum stress a material can withstand when subjected to forces that cause the material structure to slide across each other in layers, low shear fluids and occasionally metals make great lubricants.(Protolabs, 2026)

with the uneven terrain and jumps faced in the Dakar, tensile strength and shear strength are large considerations for driveshafts as the repeated up and down movements creates lots of cyclic tensile stress and the rotation also produces shear stresses throughout the shaft.

To evaluate and calculate the tensile strength a tensile test is needed to be done, a tensile test is done by fitting a material into a jig and slowly increasing the stretching force on a material measuring the change in length and the force used, this is done incrementally until the material has broken at its Ultimate Tensile Strength (UTS).

the data from this test can give the Young's modulus of a material, which is the relationship between stress within a material and the elongation percentage of a material which is called strain and is a unitless measure due to it being a ratio of length the length cancels out, another value is the yield point which is the point that a material no longer elastically deforms. (Vincent and Engler, 2011)

2.2 Hardness Testing

Hardness in motorsport can often be overlooked however rally raid events like the Dakar the terrain is extremely variable, predominantly sand, however it is what the sand hides such as boulders, rocks, stones as well as the constant sandblasting of components.

Hardness can be important to drivetrain components such as the driveshaft as if the shaft is taking repeated hits from rocks and stones, each little indentation will change the cross sectional area of the part as well as induce high stress areas where the component is no longer uniform, this can lead to failure in a variety of ways, so it is important that the driveshafts are hard enough to not deform in minor impact from objects in the stages.

A common test for hardness is the Brinell Hardness test where a sample is laid flat on an anvil and a 10mm (standard) metallic ball (harder than the material), is pushed into the material using a known force, the ball is then removed from the test subject after a fixed amount of time for settling and the dimensions of the indentation are measured, a Brinell Hardness Number (BHN) is then Calculated using the following Equation. (IEEE, 1963; Walley, 2012)

Equation 1 - Brinell Hardness Equation

$$BHN = \frac{2P}{\pi D (D - \sqrt{D^2 - d^2})}$$

Where P is the load on indenting tool (Kg), D is the Diameter of the ball, d is the diameter at rim of impression. (Industrial Physics, 2022)

2.3 Fatigue Strength Testing

Fatigue is one major factors of endurance racing and racing over tough terrain as a vehicle already is already under constant stress loading from rotational motion as well as the natural body movement, this applies to drive shafts, these experience constant cyclic loading when a vehicle is in motion, there is either the force of the engine turning the wheels or the wheels trying to turn the engine during off throttle engine braking, as well as the up and down movement from bumps and jumps. (Zhao *et al.*, 2019)

Fatigue testing can be done in various ways, however a common method of testing driveshafts would be a rotating beam method where a specimen is attached in a rotating jig, putting twist forces through a sample whether this be to plastic failure or via cyclic loading, values such as the fatigue limit in which the maximum force a material can be cycled infinitely without braking can calculated alongside other elastic values, and fatigue values. (Isakov *et al.*, 2022; Taylor, 2026)

3. Methodology

Testing of the sample Aluminium was completed using the TecQuipment ES6 Tensile test and guidance kit (TecQuipment Ltd, 2012b, 2012a).

The dimensions of the aluminium sample are recorded pre-test as this is crucial for the strain calculations, cross sectional area is also calculated the sample is then fitted into the tensile test rig as shown in Figure 2.

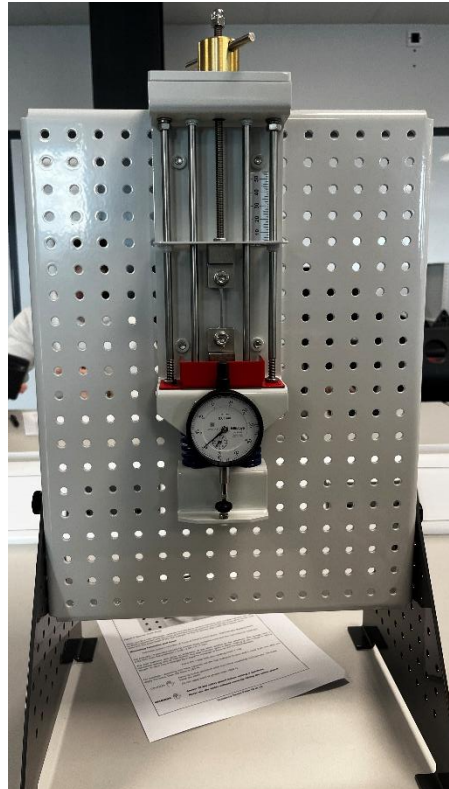


Figure 2 - ES6 TecQuipment Tensile testing machine

The sample is held into the test rig using two clamping screws at each end of the sample, note that clamping area is much larger than the cross sectional area used for testing to ensure a secure fit with maximum clamping area; It is important to fit the safety guard to the tester – this is not shown in figure 2.

Remove any backlash from the system until the dial indicator shows a very small amount of movement, aligning the top load-nut to the next nearest whole increment then set the dial indicator to 0 before starting your readings.

Rotate the load nut (Figure 6) in 0.2mm increments noting the change in the dial indicator, it is important to give the specimen a rest period to allow the full stretch to take place, this was continued until the specimen failed, force in Newtons applied to the sample is the dial indicator reading in millimetres multiplied by 100.

The extension of the specimen in mm is the number of turns of the force control being 1mm thread making the extension 1mm per turn minus the dial indicator reading. (TecQuipment Ltd, 2012b)

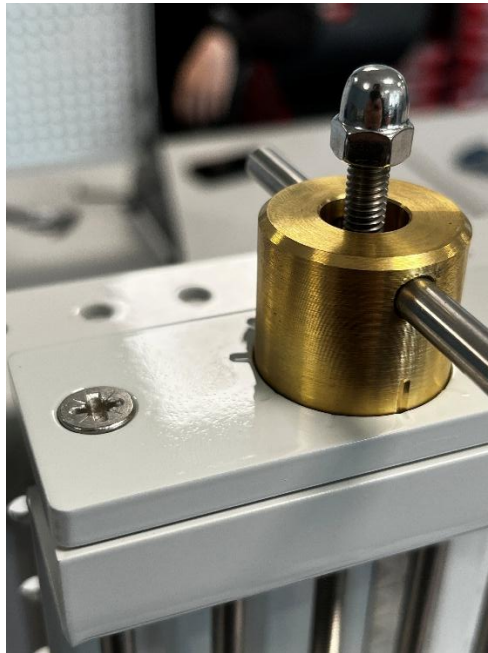


Figure 3 – Load Nut and markings from test rig.

Once the specimen has failed use the recorded data to find the yield point, young modulus, and ultimate tensile strength as seen in sections four and five.

4. Test Results

Table 1 - Raw (Column 1-2) and Processed (Column 3-6) Data from Tensile Test

Load Nut Movement (mm)	Dial Indicator (mm)	Force (N)	Extension (mm)	Stress MPa	Nominal Strain e
0	0	0	0	0.00E+00	0
0.2	0.12	12	0.08	7.02E+00	0.00257235
0.4	0.28	28	0.12	1.64E+01	0.00385852
0.6	0.46	46	0.14	2.69E+01	0.00450161
0.8	0.64	64	0.16	3.74E+01	0.00514469
1	0.84	84	0.16	4.91E+01	0.00514469
1.2	1.02	102	0.18	5.96E+01	0.00578778
1.4	1.2	120	0.2	7.02E+01	0.00643087
1.6	1.38	138	0.22	8.07E+01	0.00707395
1.8	1.57	157	0.23	9.18E+01	0.0073955
2	1.77	177	0.23	1.04E+02	0.0073955
2.2	1.96	196	0.24	1.15E+02	0.00771704
2.4	2.14	214	0.26	1.25E+02	0.00836013
2.6	2.33	233	0.27	1.36E+02	0.00868167
2.8	2.5	250	0.3	1.46E+02	0.0096463
3	2.71	271	0.29	1.58E+02	0.00932476
3.2	2.89	289	0.31	1.69E+02	0.0096785
3.4	3.07	307	0.33	1.80E+02	0.01061093
3.6	3.27	327	0.33	1.91E+02	0.01061093
3.8	3.46	346	0.34	2.02E+02	0.01093248
4	3.66	366	0.34	2.14E+02	0.01093248
4.2	3.83	383	0.37	2.24E+02	0.01189711
4.4	4.02	402	0.38	2.35E+02	0.01221865
4.6	4.2	420	0.4	2.46E+02	0.01286174
4.8	4.39	439	0.41	2.57E+02	0.01318328
5	4.58	458	0.42	2.68E+02	0.01350482
5.2	4.75	475	0.45	2.78E+02	0.01446945
5.4	4.91	491	0.49	2.87E+02	0.01575563
5.6	5.07	507	0.53	2.96E+02	0.0170418
5.8	5.21	521	0.59	3.05E+02	0.01897106
6	5.31	531	0.69	3.11E+02	0.0221865
6.2	5.39	539	0.81	3.15E+02	0.02604502
6.4	5.43	543	0.97	3.18E+02	0.03118971
6.6	5.5	550	1.1	3.22E+02	0.03536977
6.8	5.54	554	1.26	3.24E+02	0.04051447
7	5.59	559	1.41	3.27E+02	0.04533762
7.2	5.62	562	1.58	3.29E+02	0.05080386
7.4	5.68	568	1.72	3.32E+02	0.05530547
7.6	5.7	570	1.9	3.33E+02	0.06109325
7.8	5.71	571	2.09	3.34E+02	0.06720257
8	5.73	573	2.27	3.35E+02	0.07299035
8.2	5.73	573	2.47	3.35E+02	0.07942122

Table 2 - Sample Dimensions

	(mm)	(m)
Gauge Length	31.1	0.0311
Width	1.9	0.0019
Depth	0.9	0.0009
Nominal Cross Sectional Area (mm ²)	1.71	

Table 3 - Calculated Values

Yield Strength	1.88E+02
Ultimate Tensile Strength (Mpa)	3.35E+02
Youngs Modulus (Slope of Elastic Reigon Mpa)	21871.49791

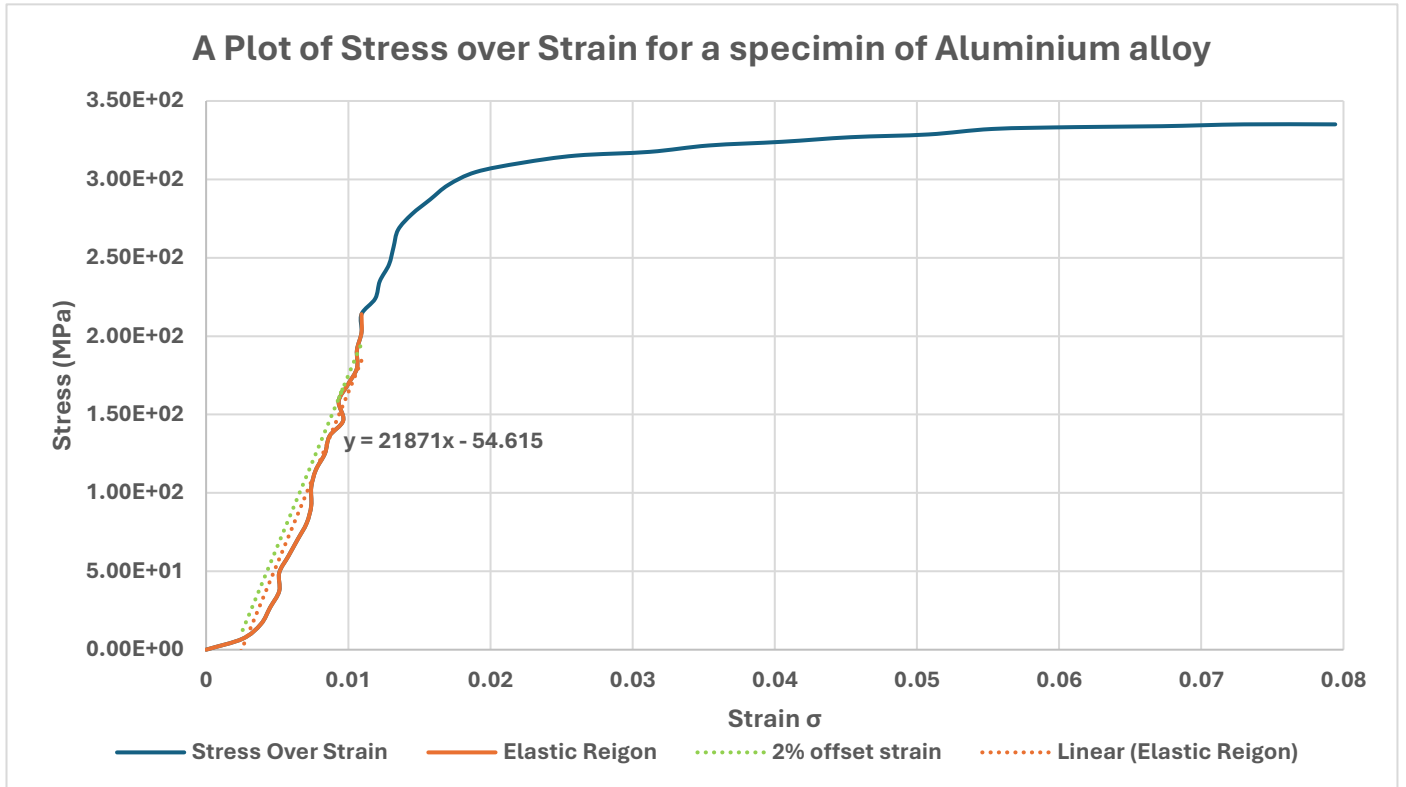


Figure 4- A Plot of Stress over Strain for a specimen of Aluminium alloy From Tensile Test

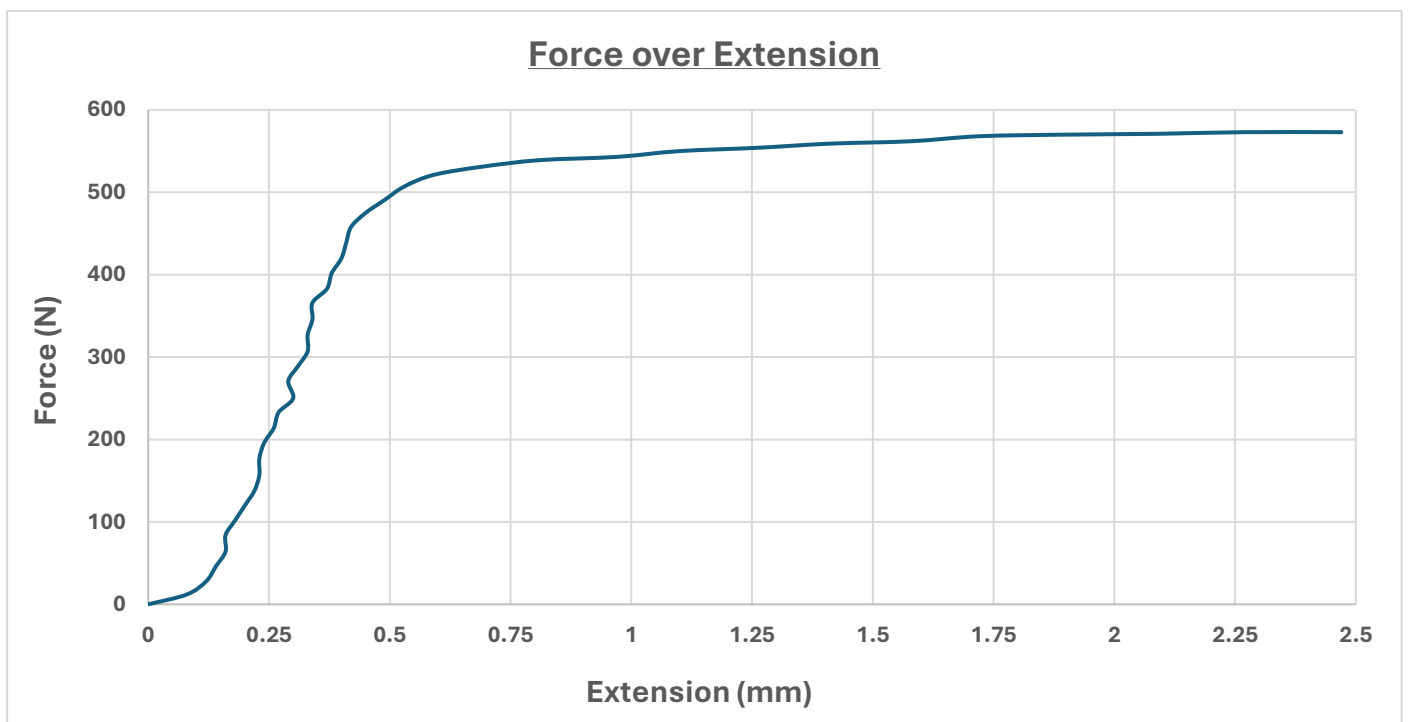


Figure 5 - A plot of Force over Extension from Tensile Test

5. Results analysis

5.1 Youngs Modulus

The amount a material can resist strain at a given strength is known as stiffness, a stiffness of a material can be quantified by its Youngs modulus (E), this is the ratio of stress at a given strain, which is a change in X over Change in Y which can be perceived as the gradient of the stress strain curve, it is crucial for the Youngs modulus to be taken from the gradient of the elastic region, before plastic Deformation begins. (TecQuipment Ltd, 2012b)

Equation 2 - Youngs Modulus

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

Data from the practical was processed within Microsoft Excel which allowed for a slope function to be used to allow for the gradient of the elastic region to be used, the top value used in the calculation was a strain of 0.01093 and a stress of 2.14×10^2 MPa, resulting in a Youngs modulus of 21.87 GigaPascals.

5.2 Yield Strength

Yield strength is the stress value in which that a material no longer elastically deforms and begins to plastically deform, it can be visually obvious on a graph, it is not as particularly obvious in figure 4, however it can be seen at the end of then elastic region.

Yield point can be decided a variety of ways the as the yield point was not obvious in this data a trendline for the elastic region was plotted with a 0.2% offset in strain, the upper point that this line intersects the stress / strain point can be considered the yield force, for the sample tested in this scenario it was **188 MPa**. (tech-calculation, no date; Protolabs, 2025)

Yield point can also be quantified using the following equation.

Equation 3 - Yield Point Quantification

$$\sigma_{yield} = \frac{\text{Force at Yield}}{\text{Original Cross Sectional area}}$$

5.3 Ultimate Tensile Strength

Ultimate tensile strength is the maximum stress a material can take before failure, this happens after plastic deformation and can be seen by the last data point on the graph this is where the data end as the sample has failed, the sample tested in the lab had a UTS of **335 MPa.**(TecQuipment Ltd, 2012b)

5.4 Strain

Strain is a unitless value as it is a ratio of length meaning the units cancel out, strain can be calculated using the following.

Equation 4 - Strain Equation

$$\epsilon = \frac{\Delta \text{Length}}{\text{Original Length}}$$

5.5 Stress

Stress is the amount of internal force a material is experiencing per unit area and can be calculated by the following.

Equation 5 - Stress Equation

$$\sigma = \frac{\text{Force}}{\text{Cross Sectional Area}}$$

5.6 Images of Test Specimen Failure

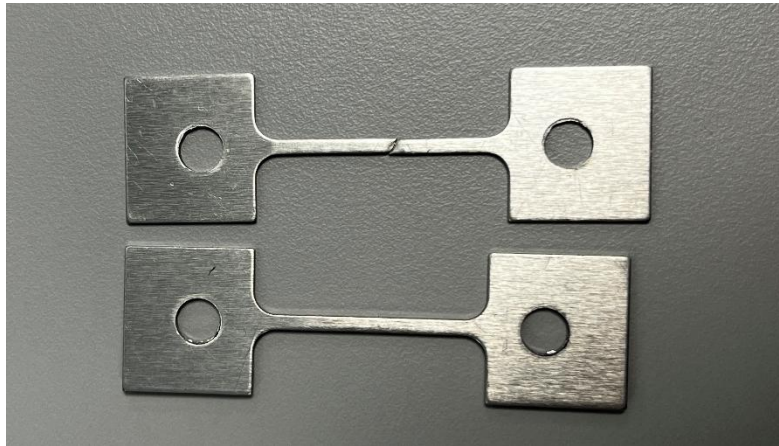


Figure 6-Failed test specimen next to original part



Figure 7 - Broken specimen with a small amount of Goose-necking

Figure 7 shows that the specimen tested did not experience a significant amount of goose necking before and at the break point, goose necking is when the cross section of a material, reduces in size due to stretching.

6. Conclusion

6.1 Failure modes

As previously discussed, failure can be caused in a variety of ways of ways, in the case of the drive shaft, the most likely cause is a fatigue shear induced by crack propagation.

The Driveshafts failed in stages four and five of the Dakar rally raids, if the material did not meet the specification of the driveshafts the failure would've happened much sooner if not instantaneously under load on a chassis dynamometer, test or a pre-stage.

Crack propagation most likely is the initiator of fatigue, cyclic loading will cause slipping on a microscopic level within the grain structure as time passed these slips cause high localised stress which in turn can cause separation within the grain structure paving the way for cracks.

A likely scenario is that a driveshaft could've been impacted by a rock as speed whilst driving or possibly damaged in shipping or installation, and indentation like this reduces the cross sectional area of the driveshaft resulting the force to be distributed over less area meaning more component stress, but the indentation also will cause high stress points in the areas that It has deformed, this type of impact will induce microcracks and high stress points in the area, once the cyclic loading starts the slipping in these areas encourage separation and a crack will then Propagate (travel) through the part, the material separation is constantly reducing the cross sectional area of the component resulting in the force being put through a smaller cross section this cycle repeats weakening the component, until the component cannot withstand the forces any longer and fails. (Chowdhury and Sehitoglu, 2016)

Figure 1 the failure of the driveshaft in section 1 supports the fatigue thesis, the image shows a dulled semi-uniform section in the top half with some striations visible which is strong evidence of a fatigue failure, furthermore the bottom almost half of the driveshaft shows, a very rough and uneven almost mountainous looking region where the shaft has most likely sheared do to a stress overload from the reduced CSA.(Fiorentin *et al.*, 2025)

6.2 Rectification to reduce further failures

The test sample provided shows that the material is not substandard in its mechanical properties and is fit for purpose as a driveshaft, however testing a broader array of samples would be advisable to eliminate anomalies, or even testing different batches to see if they're being produced with an acceptable tolerance of mechanical properties.

A postproduction finish such as superfinishing and fine polishing could assist in a stronger driveshaft, this could reduce surface imperfections and microfractures within the surface of the supplied material, which would decrease the likelihood of crack propagation and delay fatigue significantly.

Oversizing and case-hardening the driveshafts would also be an advisable finishing process as this would not reduce brittleness of the driveshaft throughout but increase the hardness and potentially toughness with the correct temper to allow the driveshafts to handle minor impacts when shipping, fitting and in use, reducing the surface imperfections which promote fatigue.

Lifecycle of the part from a team perspective needs to be reviewed also as the failed driveshafts do not appear to be marked with an identifier, in turn meaning that the driveshafts on the failed vehicles could have served more of their part life in testing stages regardless of the application and environment, fitting new zero hour parts to the vehicles would also reduce the risk of a fatigue failure.

7. References

Ashby, M.F.. (2025) *Materials selection in mechanical design*. Butterworth-Heinemann.

Chowdhury, P. and Sehitoglu, H. (2016) ‘Mechanisms of fatigue crack growth - a critical digest of theoretical developments’, *Fatigue & Fracture of Engineering Materials & Structures*, 39(6), pp. 652–674. Available at: <https://doi.org/10.1111/ffe.12392>.

Dakar.com (no date) *The race*. Available at: <https://www.dakar.com/en/dakar-world/therace> (Accessed: 1 May 2026).

Fiorentin, F.K. et al. (2025) ‘Relation Between Striations Spacing and Fatigue Crack Growth Rates for Additive Manufactured Inconel 625.’, *Fatigue & Fracture of Engineering Materials & Structures*, 48(1), pp. 454–466. Available at: <https://doi.org/10.1111/ffe.14493>.

IEEE (1963) *IEEE Std 84-1963 : IEEE Test Procedure for Determining Tensile Strength and Hardness of Lead Sheaths*, IEEE Std 84-1963. Place of publication not identified: IEEE. Available at: <https://doi.org/10.1109/IEEESTD.1963.7439695>.

Industrial Physics (2022) *Brinell Hardness Testing: How To Calculate - Industrial Physics*. Available at: <https://industrialphysics.com/knowledgebase/articles/brinell-hardness-testing-how-to-calculate/> (Accessed: 1 May 2026).

Isakov, M. et al. (2022) ‘Large-Scale Fatigue Testing Based on the Rotating Beam Method’. Available at: <https://doi.org/10.1007/s40799-022-00571-8>.

Protolabs (2025) *What Is Yield Strength? Definition, Testing and Uses*. Available at: <https://www.protolabs.com/en-gb/resources/blog/understanding-yield-strength/> (Accessed: 4 May 2026).

Protolabs (2026) *Understanding shear stress and shear load | Protolabs Network*. Available at: <https://www.hubs.com/knowledge-base/understanding-shear-stress-and-shear-load/> (Accessed: 1 May 2026).

Rogers, K. (2026) *Materials and Manufacturing Specification*.

Taylor, A. (2026) 'Fatigue Testing Conversation With Adam Taylor (MEng)'. Tarporley: Adam Taylor.

tech-calculation (no date) *Bore Diameter Calculator*. Available at: <https://tech-calculation.com/Mechanics-Calculators/Yield-Strength-Calculator/> (Accessed: 4 May 2026).

TecQuipment Ltd (2012a) *Engineering Science Worksheets TENSILE TESTER KIT ES6 TENSILE TESTS*.

TecQuipment Ltd (2012b) 'ES6 Guidance_1012'.

Vincent, L. and Engler, A.J. (2011) 'Effect of substrate modulus on cell function and differentiation', *Comprehensive Biomaterials*, 5, pp. 51–63. Available at: <https://doi.org/10.1016/B978-0-08-055294-1.00158-6>.

Walley, S. M (2012) 'Historical origins of indentation hardness testing', *Materials Science and Technology*, 28(9–10), pp. 1028–1044. Available at: <https://doi.org/10.1179/1743284711Y.0000000127>.

Zhao, L.-H. et al. (2019) 'Failure and root cause analysis of vehicle drive shaft', *Engineering Failure Analysis*, 99, pp. 225–234. Available at: <https://doi.org/https://doi.org/10.1016/j.engfailanal.2019.02.025>.