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Engineering Materials

Materials and Manufacturing (ACHA4025)

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1.Introduction

The Dakar Rally puts extreme demands on drivetrain components as they must transmit torque reliably while being exposed to continuous shock from hard landings, vibrations and cyclic stresses in severe off-road conditions. In this case two aluminium drive shafts have fractured completely while in competition, this therefore led to the retirement of both vehicles.

The design and manufacturing route had not been changed from previous successful versions however the aluminium supplier had recently changed, this makes the material condition and properties a focus for investigation

Aluminium alloys are widely used in high performance vehicle applications due to low density, good specific strength and generally corrosion resistant; however, their performance depends strongly on alloy composition, heat treatment and temper conditions (Davis, 2001; Callister and Rethwisch, 2018). Components subjected to repeated loads cannot be judged from density or appearance alone, because stiffness, strength, ductility and resistance to failure all influence whether a part performs safely (Dowling, Kampe and Milo Vanlandingham Kral, 2020; Callister and Rethwisch, 2018).

Tensile testing is a standard method to determine mechanical properties of metallic materials, including yield strength, ultimate tensile strength and elongation (Astm International, 2016). These properties are highly relevant to a driveshaft failure investigation because they indicate how a material responds to increase in tensile stress and where it has enough strength and ductility for demanding conditions.

Therefore, the aim of this assignment is to analyse the tensile test results obtained from the supplied aluminium specimen therefore able to calculate the yield strength, ultimate tensile strength and approximate young's modulus, and then use those findings alongside the observed fracture evidence and background information to identify the most likely cause of driveshaft failure. To suggest suitable preventive measures to reduce the risk of similar failures in the future.

2.Literature Review

2.1 Material requirements for a rally driveshaft

Driveshafts used in rally must combine low mass with high reliability, when in use it is required to transmit torque while being exposed to continuous load cycles, vibrations, impacts and sudden traction changes. For that reason, material selection cannot be based on tensile strength alone. The material chosen must provide adequate stiffness, ductility, toughness and fatigue resistance because a driveshaft that is strong in a static test may fail when in use if it is sensitive to crack initiation or crack growth under continuous loading (Ashby, 2017; Schijve, 2014).

For motorsport applications, weight reduction is a major objective. Aluminium alloys are commonly used because they offer low density and a favourable strength to weight ratio, which therefore reduces rotating mass and can improve vehicle response. However, low density alone is not enough to justify selection, aluminium alloys vary widely in yield strength, ultimate tensile strength, ductility and fracture resistance depending on alloying additions and temper condition (Davis, 2001; Ashby, 2017). This means even a change in supplier although the part geometry may stay the same, can alter performance significantly if the alloy grade, heat treatment or quality control changes.

2.2 Aluminium alloys and the important of grade and temper

The term “aluminium alloy” is too broad to describe capability accurately even if it is widely used structural metal. The mechanical behaviour of aluminium alloys depends strongly on composition, processing route and temper designation. Wrought and cast alloys are classified separately, and heat treatable alloys can achieve much higher strength after solution treatment and ageing than in softer conditions (Davis, 2001; Kaufman, 2000). As a result, two components that appear visually identical may perform very differently if they were supplied in a different alloy series or tempers.

This is especially important for safety critical rotating parts. High strength aluminium alloys can provide good specific performance, but they can also be sensitive to defects, surface condition and continuous loading. Unlike many other steels, aluminium alloys do not exhibit a true endurance limit which means fatigue failure can still occur at relatively low stress levels if the number of load cycles is sufficiently high (ASM INTERNATIONAL, 2012; J Schijve, 2014). Therefore, for a rally driveshaft this means both static strength and fatigue behaviour must be considered during material selection and supplier approval.

2.3 Tensile Testing a material

Tensile testing is one of the most widely used methods for assessing the mechanical behaviour of metallic materials. ASTM E8/E8M states tension testing is used to determine properties including yield strength, elongation and reduction of area (Astm International, 2016). These properties are important to the investigation as they show stress level at which permanent deformation begins, the maximum stress sustained before failure and the extent to which material can plastically deform before fracture.

The stress strain curve obtained from the tensile testing also provides information about stiffness through the slope of the elastic region, commonly expressed as young's modulus. In engineering design, stiffness is important because it governs how much a component deforms under load, while yield strength and ultimate tensile strength describe the onset of permanent deformation and final resistance to fracture (Callister and Rethwisch, 2018; Dowling, 1993). Tensile Testing is therefore the first useful step in failure investigation because it helps determine whether the supplied material is broadly consistent with the expected behaviour of a suitable alloy. Tensile testing however cannot fully characterise real world performance in a drive shaft as they are often governed by fatigue, stress concentrations and manufacturing defects rather than overload alone (Dowling, 1993; Hou et al., 2022)

3.Methodology

3.1 Equipment and specimen

The experiment was carried out using the tensile tester kit provided, which is designed to investigate the tensile properties of materials, including aluminium alloys, steel, PVC and duralumin. The rig applies tensile loading to a flat specimen by turning a load nut at the top of the machine, while a dial indicator measures the spring deflection used to determine the applied force.

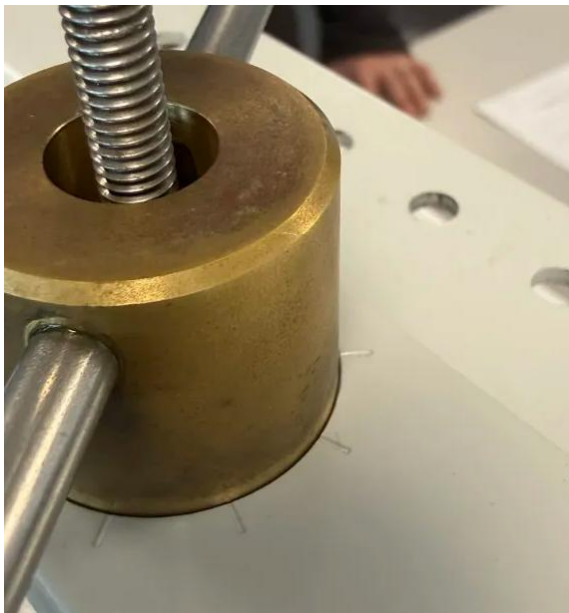


Figure 2 Load Nut located at the top of tensile tester kit

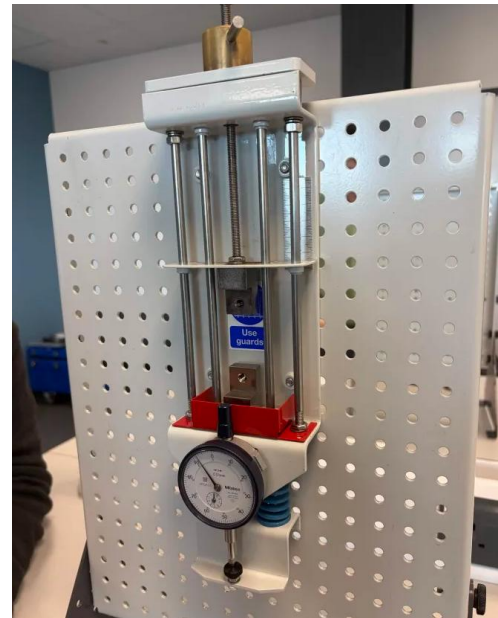


Figure 1 Tensile Tester kit used for investigation

Only one specimen was tested in the investigation, which was aluminium. Before testing, the specimen was measured with a dial calliper. The measured gauge length was approximately 30.9mm, while specimen thickness and width were approximately 1mm and 2mm, giving a cross-sectional area of about 2mm^2 .



Figure 4 Dial calliper used to measure length



Figure 3 Aluminium Specimen after fracture

3.2 Experimental procedure

The tensile tester was first mounted securely onto the work panel as seen in figure 2, the aluminium specimen was fitted into the top and bottom chucks of the machine and clamped into position. After the specimen had been installed, the dial indicator was set to zero before loading began.

The test was then carried out gradually by turning the load nut seen in figure 1 in clockwise with small increments, readings were taken at 0.2mm intervals, each line around the load nut as seen in figure 1 represented a movement of 0.2mm. At each increment, the corresponding dial indicator reading was recorded manually into a data table. The specimen fractured at a total load nut movement of 4.9mm

3.3 Data processing

After the experimental readings had been recorded, the dial indicator values were converted into force, extension, stress and nominal strain. The applied force was calculated from the dial indicator reading used the combined spring rate of 100N/mm provided in the guidance notes (E36 Guidance Notes, 2012).

$$Force (N) = Dial\ indicator\ reading\ (mm) \times 100$$

The specimen extension was then calculated by subtracting the dial indicator readings from the load nut movement:

$$Extension\ (mm) = Load\ nut\ movement\ (mm) - Dial\ indicator\ reading\ (mm)$$

Stress was calculated by dividing the applied force by the original cross-sectional area of the specimen, while nominal strain was calculated by dividing the extension by the original gauge length. These calculations are consistent with the theory presented in the guidance notes, where stress is defined as force divided by area and strain as change in length divided by original length (E36 Guidance Notes, 2012)

The processed data were then entered into excel to produce a results table, from these values graphs of force against extension and stress against nominal strain were plotted. The stress strain graph was used to estimate yield stress, ultimate tensile strength and the gradient of the elastic region. This gradient was used to estimate young's modulus

Table 1 Data from experiment processed in excel

Load Nut movement (mm)	Dial Indicator (mm)	Force (N)	Extension (mm)	Stress (MPa)	Nominal Strain
0.0	0.00	0.0	0.00	0.0	0.0000
0.2	0.16	16.0	0.04	8.0	0.0013
0.4	0.34	34.0	0.06	17.0	0.0019
0.6	0.51	51.0	0.09	25.5	0.0029
0.8	0.69	69.0	0.11	34.5	0.0036
1.0	0.87	87.0	0.13	43.5	0.0042
1.2	1.05	105.0	0.15	52.5	0.0049
1.4	1.20	120.0	0.20	60.0	0.0065
1.6	1.37	137.0	0.23	68.5	0.0074
1.8	1.54	154.0	0.26	77.0	0.0084
2.0	1.70	170.0	0.30	85.0	0.0097
2.2	1.86	186.0	0.34	93.0	0.0110
2.4	2.05	205.0	0.35	102.5	0.0113
2.6	2.20	220.0	0.40	110.0	0.0129
2.8	2.35	235.0	0.45	117.5	0.0146
3.0	2.45	245.0	0.55	122.5	0.0178
3.2	2.57	257.0	0.63	128.5	0.0204
3.4	2.65	265.0	0.75	132.5	0.0243
3.6	2.74	274.0	0.86	137.0	0.0278
3.8	2.81	281.0	0.99	140.5	0.0320
4.0	2.89	289.0	1.11	144.5	0.0359
4.2	2.95	295.0	1.25	147.5	0.0405
4.4	2.97	297.0	1.43	148.5	0.0463
4.6	3.04	304.0	1.56	152.0	0.0505
4.8	2.97	297.0	1.83	148.5	0.0592
5.0					
6.0					
7.0					
8.0					
9.0					
10.0					
20.0					
30.0					
40.0					
50.0					
60.0					

3.4 Limitations

Only one aluminium specimen was tested, so the results could not be averaged or compared against repeat examples. This reduces confidence in the consistency of measured properties. Second, the final gauge length after the fracture was not measured during the practical session, meaning that percentage elongation could not be determined directly and would only be estimated if required. Third the E36 guidance notes explain that the machine measures nominal strain rather than true local strain across the gauge length, because some of the measured movement included deformation within the machine itself rather than the specimen alone. As a result, the young's modulus from the graph should be treated as an approximation (E36 Guidance Notes, 2012)

4. Test results

A tensile test was carried out on aluminium specimen which was provided, using the tensile tester kit. The measured gauge length was 30.9mm and the cross-sectional area was taken as 2mm² from the specimen dimensions. Raw indicator readings were converted into force, extension, stress and nominal strain.

The processed results are shown in Table 1 in Methodology, with force vs extension and stress vs nominal strain presented in figures 5 and 6 below.

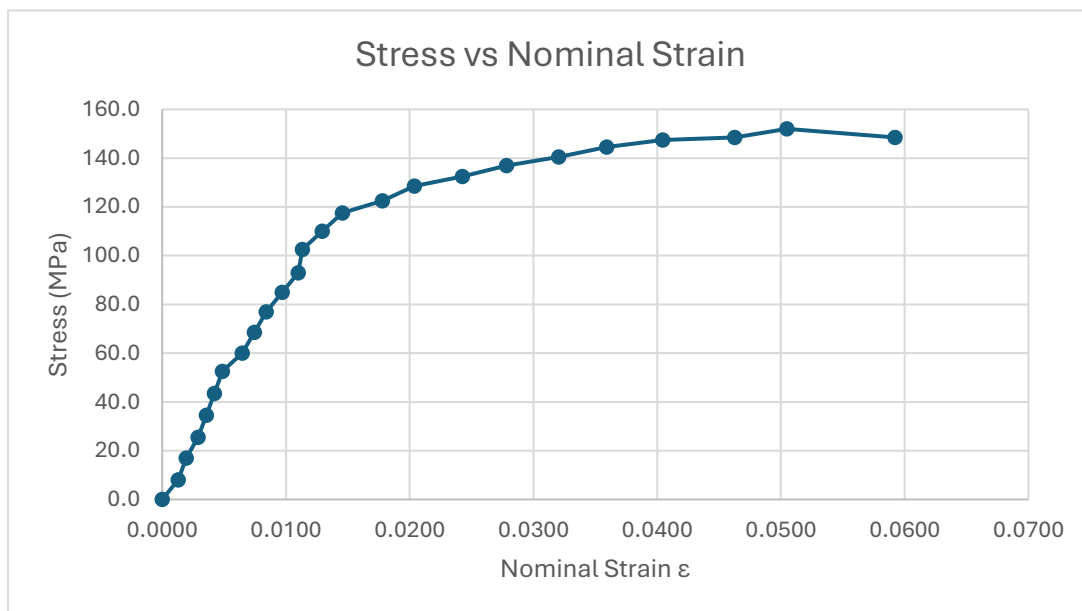


Figure 6 Stress Vs Nominal Strain for aluminium specimen

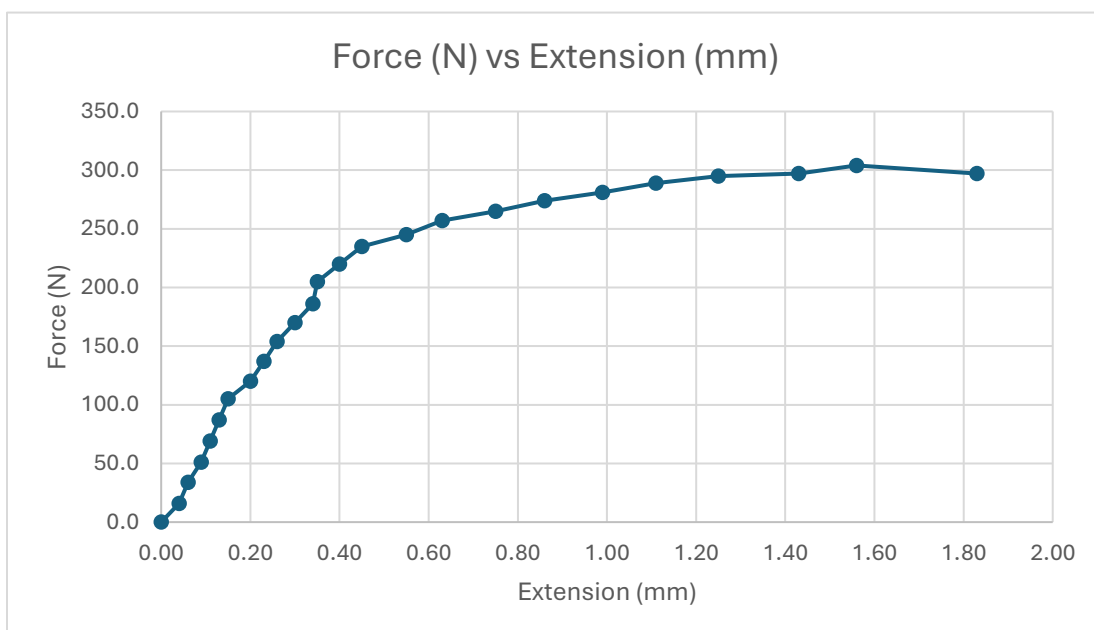


Figure 5 Force Vs Extension for aluminium specimen

5. Analysis and Discussion

The stress nominal strain graph was used to determine three properties, yield strength, ultimate tensile strength and young's modulus. The curve showed an initial near linear elastic region, followed by a decrease in gradient as the aluminium specimen began to yield. The yield strength was estimated from the first clear deviation from the linear portion of the graph at approximately 60 MPa.

The ultimate tensile strength (UTS) was determined from the maximum recorded load during the experiment. The highest dial indicator reading was 3.04mm, which corresponds to a force of 304N using the relation:

$$Force = dial\ indicator\ reading \times 100$$

Using the measured cross-sectional area of 2mm², the maximum stress was:

$$UTS = \frac{F}{A} = \frac{304}{2} = 152\ N/mm^2 = 152\ MPa$$

Therefore, the UTS of the specimen was 152 MPa. The slight reduction in stress at the final recorded point showed that the specimen has passed its peak load and was close to final fracture.

The Young's modulus was estimated from the gradient of the intimal straight-line region of the stress nominal strain graph using:

$$E = \Delta\sigma / \Delta\varepsilon$$

A linear trendline fitted to the early elastic data produced the equation:

$$y = 12254x - 8.1679$$

Since the graph plots stress (MPa) against nominal strain, the gradient of the line is the modulus. Therefore, the Youngs modulus was:

$$E = 12254\ MPa = 12.254\ GPa \approx 12.3\ GPa$$

This value is much lower than the published modulus for aluminon alloys (Davis, 2001) but this can be explained by the fact that the tensile test rig measures nominal strain, so some of the measured displacement comes from the apparatus as well as the specimen, For this reason, the modulus obtained should be treated as an apparent value rather than a precise material constant. The results are important when compared with the operating stress given, which was 90 MPa, since 90 MPa is above the measured yield strength of 60 MPa, the material would be expected to undergo plastic defamtion in service rather than remaining fully elastic.

This suggest that the tested aluminium did not provide a sufficient safety margin for a rally driveshaft application, the design and production method were unchanged. The most likely cause of failure was a material related issue, such as an incorrect alloy grade, unsuitable temper condition or reduced material quality. The driveshaft failed due to progressive damage under load, followed by the final overload when the remaining cross section could no longer support the applied stress.

6. Conclusion

Overall this report investigated the failure of an aluminium driveshaft used in Dakar Rally vehicles by analysing tensile test data from the specimen which was provided and comparing the results with the operating conditions given, the tensile test showed a yield strength of approximately 60 MPa, an ultimate tensile strength of 152 MPa, and Youngs Modulus of 12.3 GPa. Although the modulus is lower than published values for aluminium alloys, this is due to the rig measuring nominal strain rather than true specimen strain.

The most significant finding was the operating stress from the Dakar of 90 Mpa exceeded the yield strength of the tested material. This indicates that the driveshaft material was likely unsuitable for the applied conditions and would have undergone plastic deformation in use. Since the design and production method remained unchanged, the most likely cause of failure was a material related issue associated with the supplier change, such as an incorrect alloy, unsuitable temper or reduced material quality.

To prevent similar failures in future, the team should introduce tighter supplier control, verify alloy grade and temper through material certification, and carry out batch validation tests such as tensile or hardness testing before the driveshafts are approved

7. References

- Ashby, M. (2017). *Materials selection in mechanical design*. 5th ed. Amsterdam: Butterworth-Heinemann.
- ASM INTERNATIONAL (2012). A.SM INTERNATIONAL.
doi:<https://doi.org/10.31399/asm.tb.ffub.9781627083034>.
- Astm International (2016). *Standard test methods for tension testing of metallic materials*. West Conshohocken, Pa, United States: Astm International.
- Callister, W.D. and Rethwisch, D.G. (2018). *Materials Science and Engineering: An Introduction*. 10th ed. Hoboken, Nj: Wiley.
- Davis, J.R. (2001). Aluminum and Aluminum Alloys. *Alloying: Understanding the Basics*. [online]
doi:<https://doi.org/10.1361/autb2001p351>.
- Dowling, N.E. (1993). *Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue*. [online] Google Books. Prentice Hall. Available at:
https://books.google.co.uk/books/about/Mechanical_Behavior_of_Materials.html?id=NJNRAAAAMAAJ&redir_esc=y.
- Dowling, N.E., Kampe, S.L. and Milo Vanlandingham Kral (2020). *Mechanical behavior of materials : engineering methods for deformation, fracture, and fatigue*. Harlow: Pearson Education Limited.
- E36 Guidance Notes (2012). *Engineering Science Guidance Notes TENSILE TESTER KIT ES6*.
- Hou, N., Ding, N., Qu, S., Guo, W., Liu, L., Xu, N., Tian, L., Xu, H., Chen, X., Zaïri, F. and Lawrence Wu, C.-M. (2022). Failure modes, mechanisms and causes of shafts in mechanical equipment. *Engineering Failure Analysis*, 136, p.106216.
doi:<https://doi.org/10.1016/j.engfailanal.2022.106216>.
- J Schijve (2014). *Fatigue of structures and materials*. Springer.
- Kaufman, J.G. (2000). Understanding Wrought and Cast Aluminum Alloys Designations. 3.
doi:<https://doi.org/10.1361/iaat2000p023>.