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1. Introduction

The following report will discuss findings from an investigation into driveshaft failure (Figure 1) after a team competed in the Dakar rally and was forced into retirement because of this occurrence. While the components were assembled identically to previous iterations, the change in material supplier corresponds with the timing of the failure, leaving the grade and temper of the material in question.

A physical test will be conducted using a sample of the aluminium, to collect data to aid calculations used to determine the specific grade of the material. The test methodology will be outlined, providing a clear view of the process used.

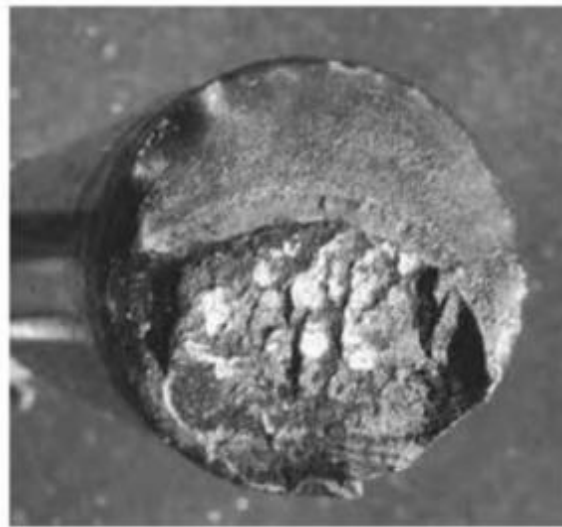


Figure 1 - Failed Driveshaft presented for enquiry (Rogers, 2026)

2. Literature Review

Choosing a material for this application would be an extensive process that would require real world testing within a given team's budget, alongside using existing research to choose the most appropriate material. For example, when choosing a torsional shaft such as an anti-roll bar, a team would likely research different material's ability to resist repeated torsion occurrences without deforming over an extended period of time to ensure that they don't have to replace the part frequently. They would also need to look into its elasticity to find the correct stiffness for application. For example, a road going car like an SUV would have a roll bar that would allow more body roll, however a sport orientated vehicle would have a tighter set up for cornering, which would require a stiffer bar that is able to withstand more load before starting to twist.

Aspects like weight durability and cost are all taken into consideration when selecting the material.

Different tests used in industry to investigate materials include the following:

The tensile test. This is performed as part of the investigation according to the assignment brief, outlined in section 2 and its subsections.

Due to the nature of the rally being designed to push vehicles to the limit (www.dakar.com, n.d.), toughness and hardness testing should be performed on the material.

Charpy impact test. This toughness testing is usually performed using a specimen secured in place below a pendulum-testing machine. First working out the potential energy of the pendulum, the test is then performed: Iowa State University (2021) states delivery of a single overloading event provides a strike to the material, breaking through it before its upswing. The final height of the pendulum is recorded after breaking through the specimen. Impact toughness of the material is then determined by measuring the energy absorbed in the event. (Figure 2)

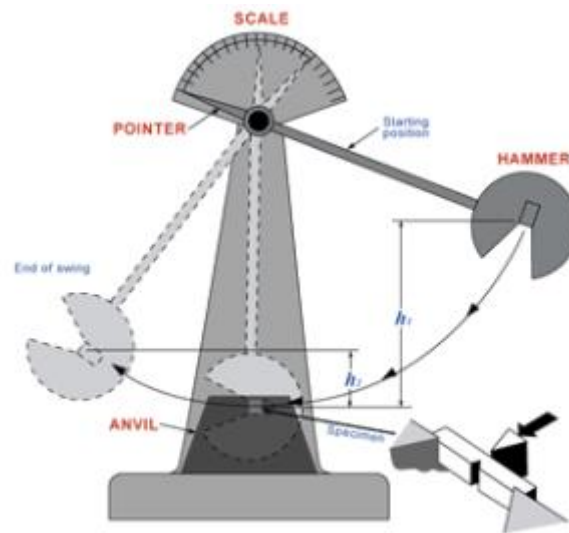


Figure 2- Charpy Test Diagram (Iowa State University, 2021)

The *Brinell hardness test* is another test used to determine a material's resistance to permanent indentation. It is performed by pressing a tungsten-carbide ball into a material and measuring the indentation against the diameter of the ball. (Freudenberger, Vernes and Fotiu, 2023)

The *Vickers test* is used for the same purpose as the *Brinell test*, however produces an indentation that is easier to measure due to use of a pointed press, rather than pressing a ball. (btiernay, 2022)

The *Mohs test* is also relevant to the application as it measures a material's resistance to scratches in comparison to other materials along the *Mohs hardness scale*. This test is an industry standard and is often also used in the mobile phone industry to compare different screen resistances to being scratched by objects such as keys that are found in pockets.

While the manufacturing process was the same as reported in the assignment brief, any surface imperfections or finishes present in the component when bolted to the car would have been shared with the previous component. The change in manufacturer potentially results in a different grade of alloy with a change in its material properties, which is why testing should be done to assess material properties.

Testing the impact toughness, material hardness and resistance to scratching is important as the rally would expose the driveshafts to repeated impact and abrasive occurrences (such as sand being projected at the shafts from the tyres) as the vehicles cover the stage.

These occurrences could introduce imperfections into the components, which could cause premature failure as these imperfections act as stress concentrators within the component's operation.

The nature of a driveshaft will put it through repeated torsional cycles, highlighting the need for torsional testing of components. The testing for this includes securing a specimen into a chuck and applying torsional loads to it, either with a machine, or by hanging weights off a rotating chuck on the other side of the specimen. Testing can either evaluate a component's behaviour under constant load, load cycling or increasing load until failure.

3. Methodology

3.1 - Equipment

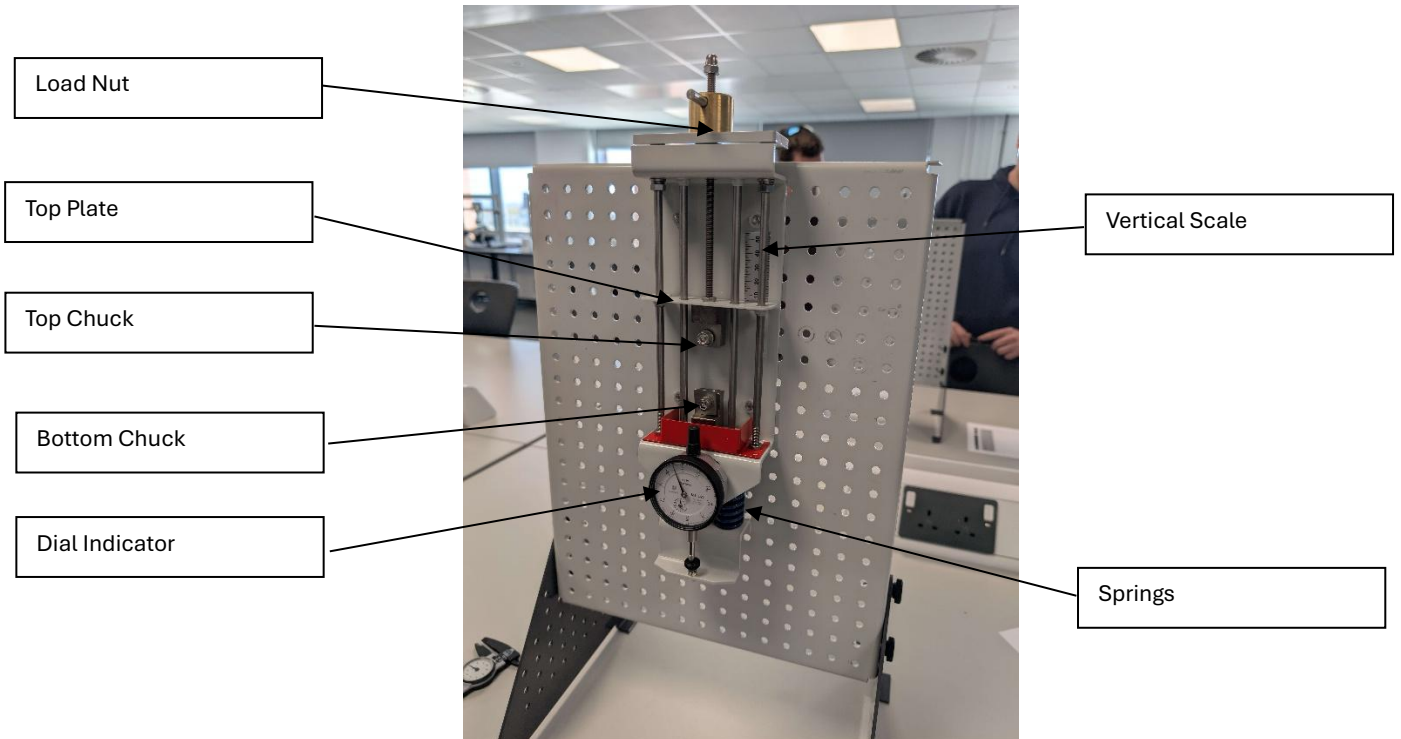


Figure 3 - Testing Equipment, Engineering Science Tensile Tester Kit ES6 (Taken During Testing)

Figure 3 shows the equipment needed from the 'Tensile Tester Kit ES6' set up on a work panel to give an understanding of how it should look prior to commencing tests.

Figure 4 below shows the aluminium specimen secured.

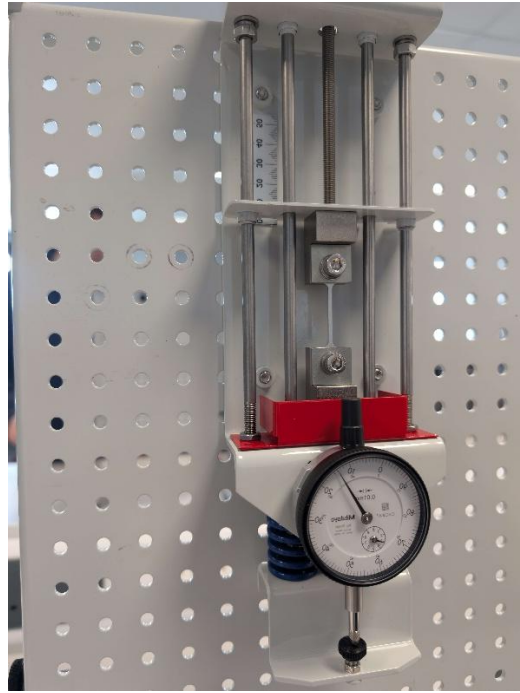


Figure 4 - Specimen Secured in the chucks of the test kit

3.2 - Background Test Information.

This test is a destructive test that provides data for the Yield strength, Tensile strength and elongation of a material. It does this by adding an axial load or force to a specimen until failure.

The load nut at the top of the tester pulls the top chuck upwards, and has a small notch and scale divided into ten increments that helps you observe how far you have rotated the nut each turn. The top chuck pulls the specimen upwards 1mm per complete rotation, and the scale of the top nut shows an upward pull of 0.1mm per increment.

Essentially, this test pulls the test specimen apart until failure.

The dial indicator shows the force on the specimen by measuring the spring deflection according to *Hooke's Law*. (TechQuipment 2012)

3.3 – Test Procedure

Before any testing commences, zero the gauge after fitting the specimen.

Carefully turn the load nut clockwise until the dial indicator shows a small movement, stopping when the load nut is aligned with one of its scale marks. Next, turn the outer bezel of the dial indicator to align the pointer to the zero value. Doing so takes up any slack in the system, ensuring that any measurements recorded are true to the force going through the specimen only.

When testing in real world applications, samples can be taken from specific components, however using this kit, the sample was provided using specially made specimens.

Once Zeroed, note the reading on the vertical scale. The '*TechQuipment Tensile test*' Booklet (2012) states that the load nut should be rotated in small 0.2mm steps up to 5mm, then larger 1mm and 10mm steps until breakage. As the team was only testing one material, they had more time to complete the testing, so opted to continue in 0.2mm increments until breakage in order to hopefully compile a larger data set.

Specimen length can be visually compared in Figure 5, where the overall extension of the specimen is shown by placing the failed piece next to another piece provided in the test kit. Both pieces were manufactured to the same specifications as shown in Figure 6

Original length: 30mm

After testing: 32.1mm



Figure 5 - Tested specimen compared to datum specimen

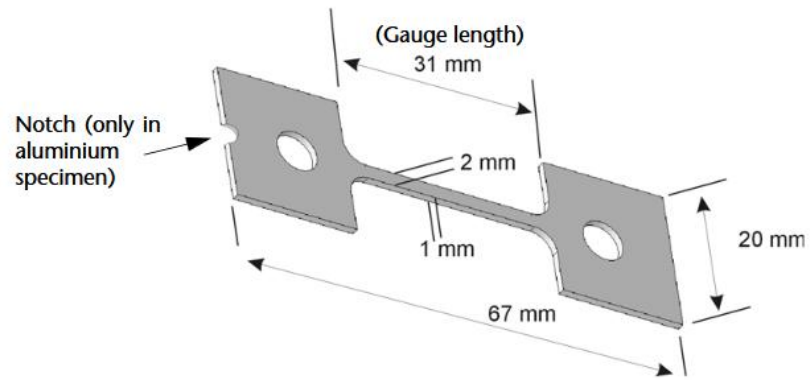


Figure 6 - Specimen dimensions (ES6 Guidance book, TechQuipment Ltd, 2012)

4. Data

Table 1 – Experiment Data

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	0.14	14	0.06	7	0.002
0.4	0.31	31	0.09	15.5	0.003
0.6	0.49	49	0.11	24.5	0.003666667
0.8	0.66	66	0.14	33	0.004666667
1	0.85	85	0.15	42.5	0.005
1.2	1.05	105	0.15	52.5	0.005
1.4	1.24	124	0.16	62	0.005333333
1.6	1.43	143	0.17	71.5	0.005666667
1.8	1.62	162	0.18	81	0.006
2	1.8	180	0.2	90	0.006666667
2.2	2	200	0.2	100	0.006666667
2.4	2.19	219	0.21	109.5	0.007
2.6	2.38	238	0.22	119	0.007333333
2.8	2.57	257	0.23	128.5	0.007666667
3	2.76	276	0.24	138	0.008
3.2	2.95	295	0.25	147.5	0.008333333
3.4	3.14	314	0.26	157	0.008666667
3.6	3.33	333	0.27	166.5	0.009
3.8	3.51	351	0.29	175.5	0.009666667
4	3.69	369	0.31	184.5	0.010333333
4.2	3.89	389	0.31	194.5	0.010333333
4.4	4.08	408	0.32	204	0.010666667
4.6	4.25	425	0.35	212.5	0.011666667
4.8	4.43	443	0.37	221.5	0.012333333
5	4.61	461	0.39	230.5	0.013
5.2	4.76	476	0.44	238	0.014666667
5.4	4.91	491	0.49	245.5	0.016333333
5.6	5.1	510	0.5	255	0.016666667
5.8	5.07	507	0.73	253.5	0.024333333
6	5.15	515	0.85	257.5	0.028333333
6.2	5.21	521	0.99	260.5	0.033
6.4	5.24	524	1.16	262	0.038666667
6.6	5.29	529	1.31	264.5	0.043666667
6.8	5.34	534	1.46	267	0.048666667
7	5.4	540	1.6	270	0.053333333
7.2	5.45	545	1.75	272.5	0.058333333
7.4	5.45	545	1.95	272.5	0.065
7.6	5.9	590	1.7	295	0.056666667
7.8	5.9	590	1.9	295	0.063333333
8	5.9	590	2.1	295	0.07

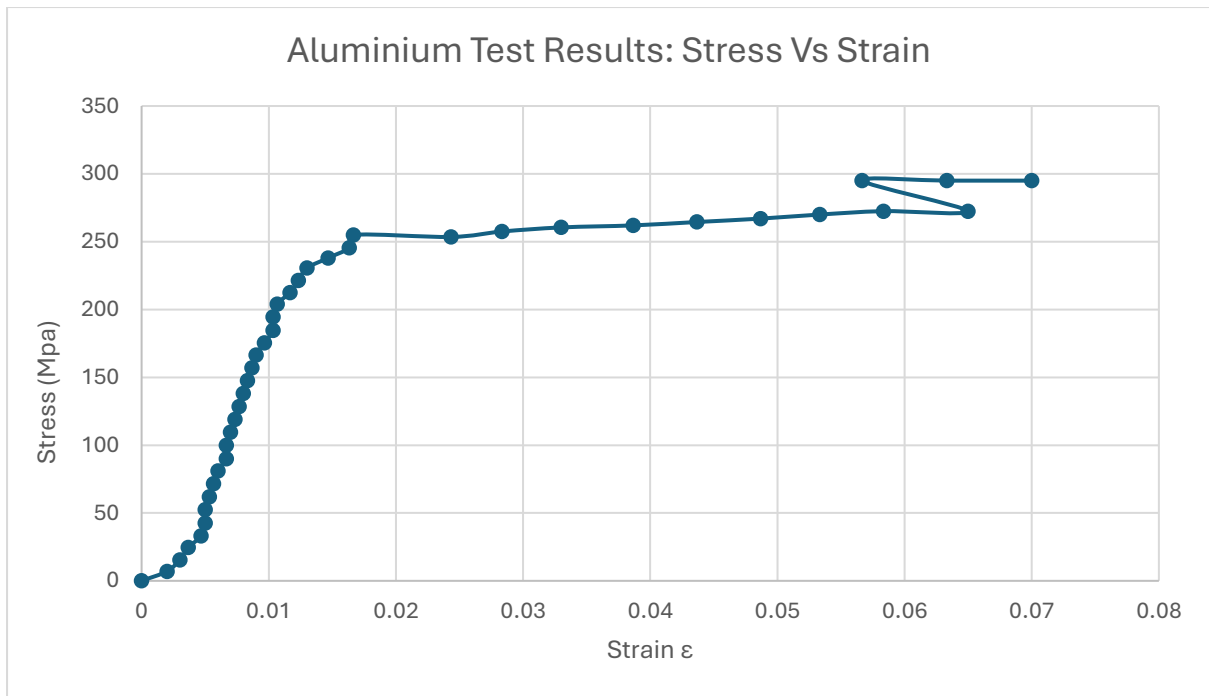


Figure 7 - Graph of Stress Vs Strain

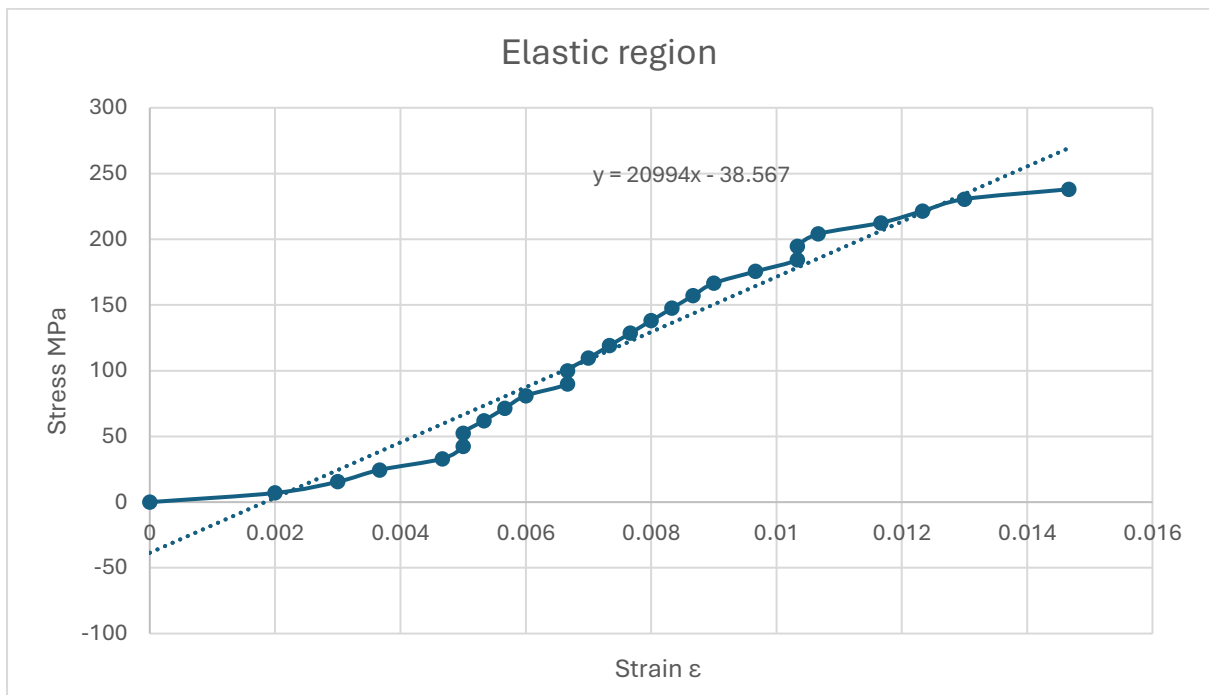


Figure 8 - Young's Modulus Graph

Points to note: -

Following the guidance provided in the TechQuipment handout (2012), each dial indicator reading should be double checked. After 7.0 mm of load nut movement, the readings start to repeat. This is where the specimen is rapidly approaching its elastic limit and has started to experience creep. The time taken to double check the dial indicator here allows the material to stretch, thus taking up some of the load being applied. At this point, the material starts to deform, which was visible in the presence of necking upon inspection of the specimen after testing. (seen in Figure 9) This deformation is why some of the results for applied forces repeat.

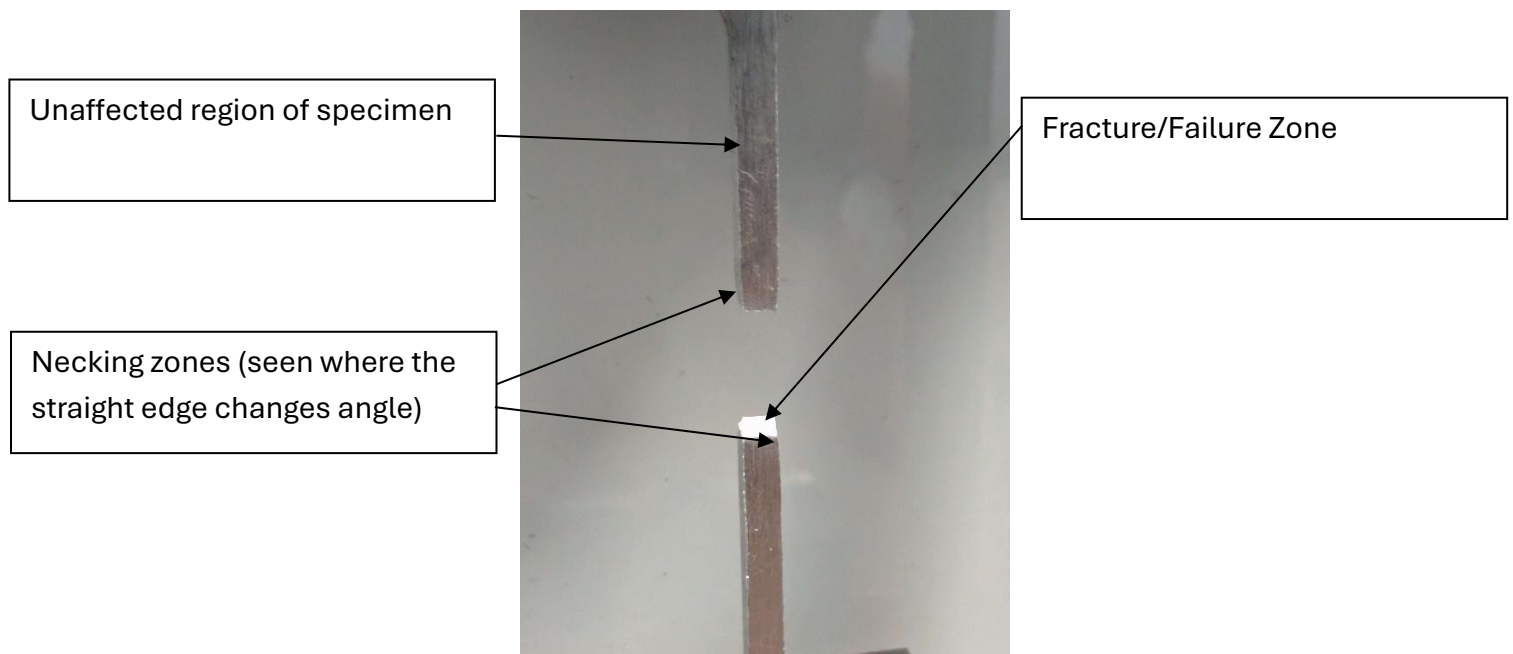


Figure 9 - Necking Observed after testing

Towards the end of testing, it was observed that the dial indicator reading decreased after the load nut was rotated, which supports this argument for the repeated results. This can also be seen at the end of the graph (Figure 7), where the strain values jolt backwards, as the readings have started to repeat due to the material stretching.

4.1 –Equations Relating to Test Data

Values obtained from Figures 7,8 and Table 1.

- Yield Strength: $\frac{\text{Force (at point of plastic deformation, N)}}{\text{Original Cross Sectional Area}}$
At 5.2mm of load nut movement (point where elastic deformation becomes plastic): $\frac{476}{0.03} = 16227.27273 \text{ Nm}^2$
- Ultimate Tensile Strength: $\frac{\text{Maximum Force During test (N)}}{\text{Original Cross Sectional Area (m)}} \text{ (Xometry, 2023)}$
UTS: $\frac{590}{0.03} = 19666.66667 \text{ Nm}^2$
- Young's Modulus: $\frac{\text{Stress}}{\text{Nominal strain}}$
At 4.2 mm of Load nut movement: $\frac{194.5}{0.010333333} = 18822.58065 \text{ Pa or } 1.88 \text{ GPa}$

5. Data Discussion

The brief for this assignment states that the maximum force applied during operation was 90Mpa. The sample given during testing withstood forces until its yield strength at 250Mpa as seen in Figure 7, before reaching its elastic limit and starting to permanently deform. This indicates that the component did not fail due to the forces applied being too strong, but more likely gave in to fatigue during repeated stress cycles during operation.

Figure 8 shows a graph of the elastic region of the material, which is the initial phase of a material's stress-strain curve, where deformation is non-permanent. (Psu.edu, 2025)

Another notable factor is that the test performed does not give an accurate reading for young's modulus (TechQuipment Ltd, 2012). In order to collate data accurately for strain, an extensometer is used. This is an expensive and delicate device that was not available for this test.

6. Conclusion

Figure 1, re-displayed for convenience here as Figure 10, shows the cross-sectional area after failure of the component in question. Figure 11 shows the cross-sectional area of a bolt after a fatigue failure. Figure 12 shows a diagram of the same type of failure. The figures all look visibly similar indicating the same type of fracture with the driveshaft component.

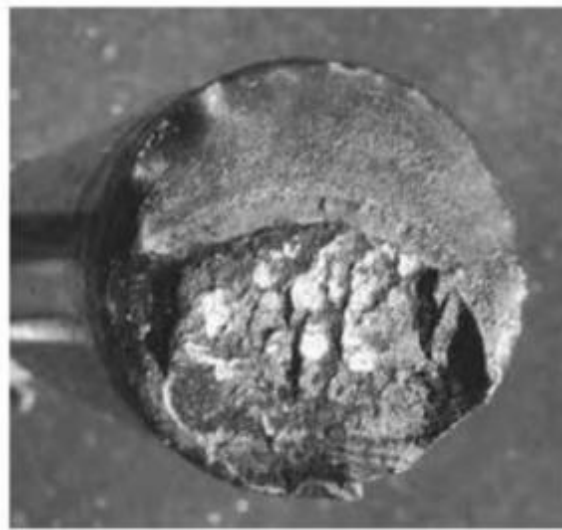


Figure 10 - Failed component, (Rogers, 2026)

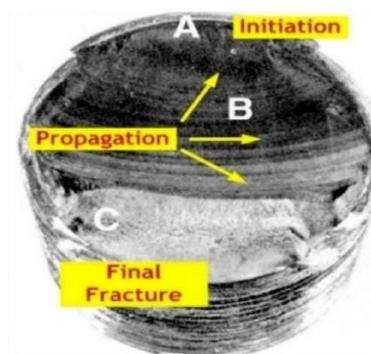


Figure 11 - Fatigue failure of a bolt (Amit Kaimkuriya, Sethuraman and Gupta, 2024)

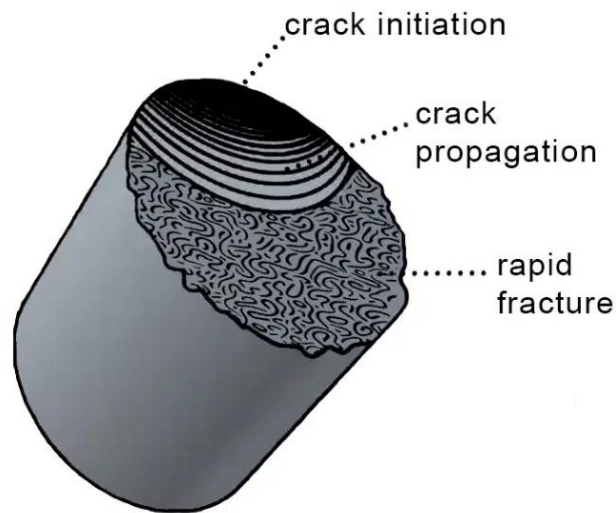


Figure 12 - Diagram of Fatigue Cross Section - (The Armoloy Corporation, 2023)

Investigating further, Figure 13 from Yena Engineering (2020) shows multiple cross-sectional diagrams of fatigue failures. In this figure, the second and third images from the high nominal stress section *Tension-tension or tension compression* indicate that this is the type of fatigue failure present. Below there is a close up of Figure 13 compared to the cross-sectional area of the actual component shown in Figures 1 and 10.

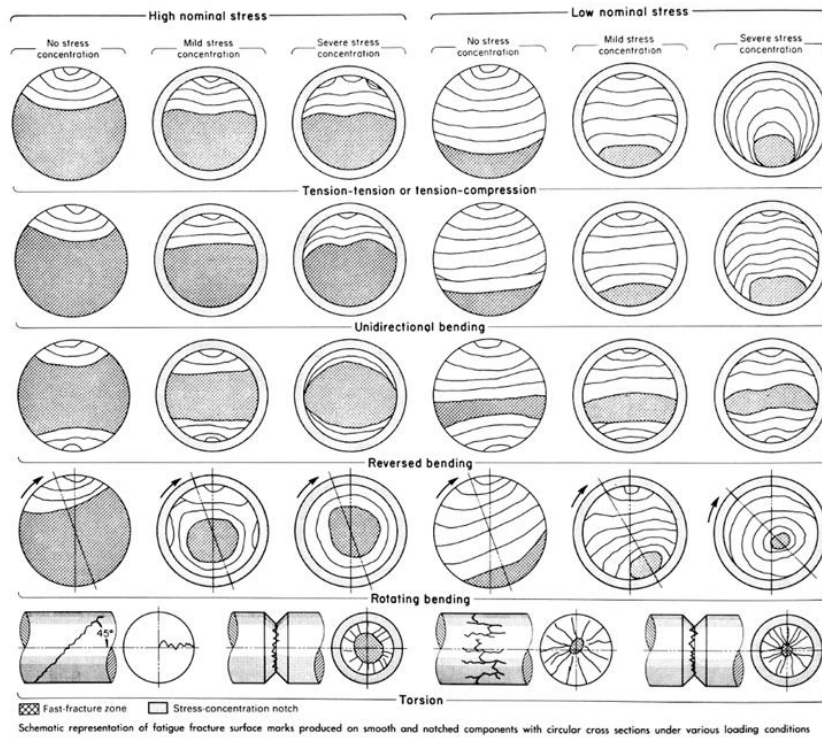
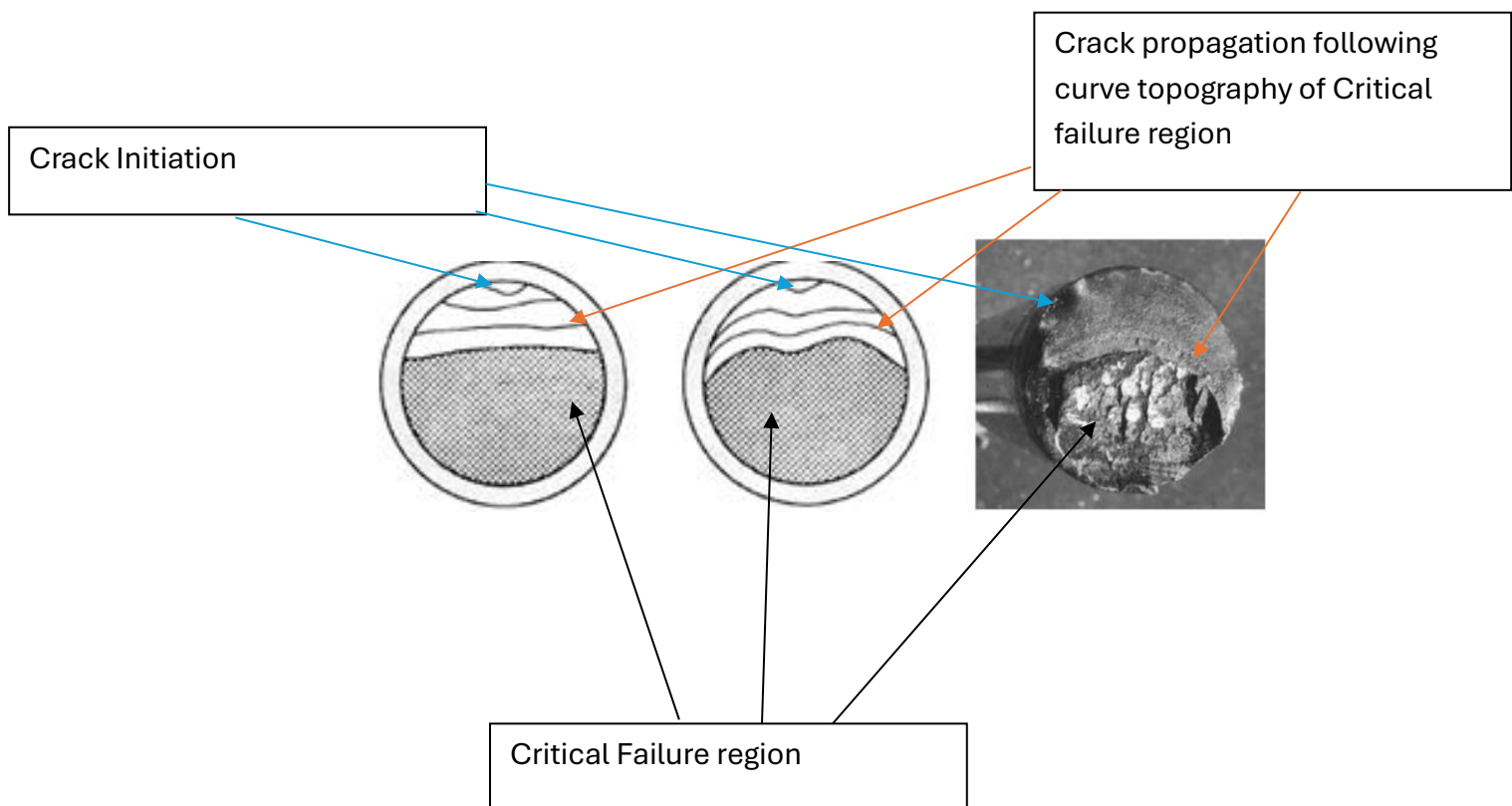


Figure 13 - Multiple Cross Section Diagrams (Yena Engineering, 2020)



Tension-Tension or Tension Compression failure makes sense in this application for the following reasons: -

- Torque applied to a driveshaft would have to overcome resistances in the wheel bearing and the contact patch of the tyre
- During rotation, forces heading in the direction of the contact patch would put that side of the component under compression
- Forces rotating away from the contact patch would apply tension to the component

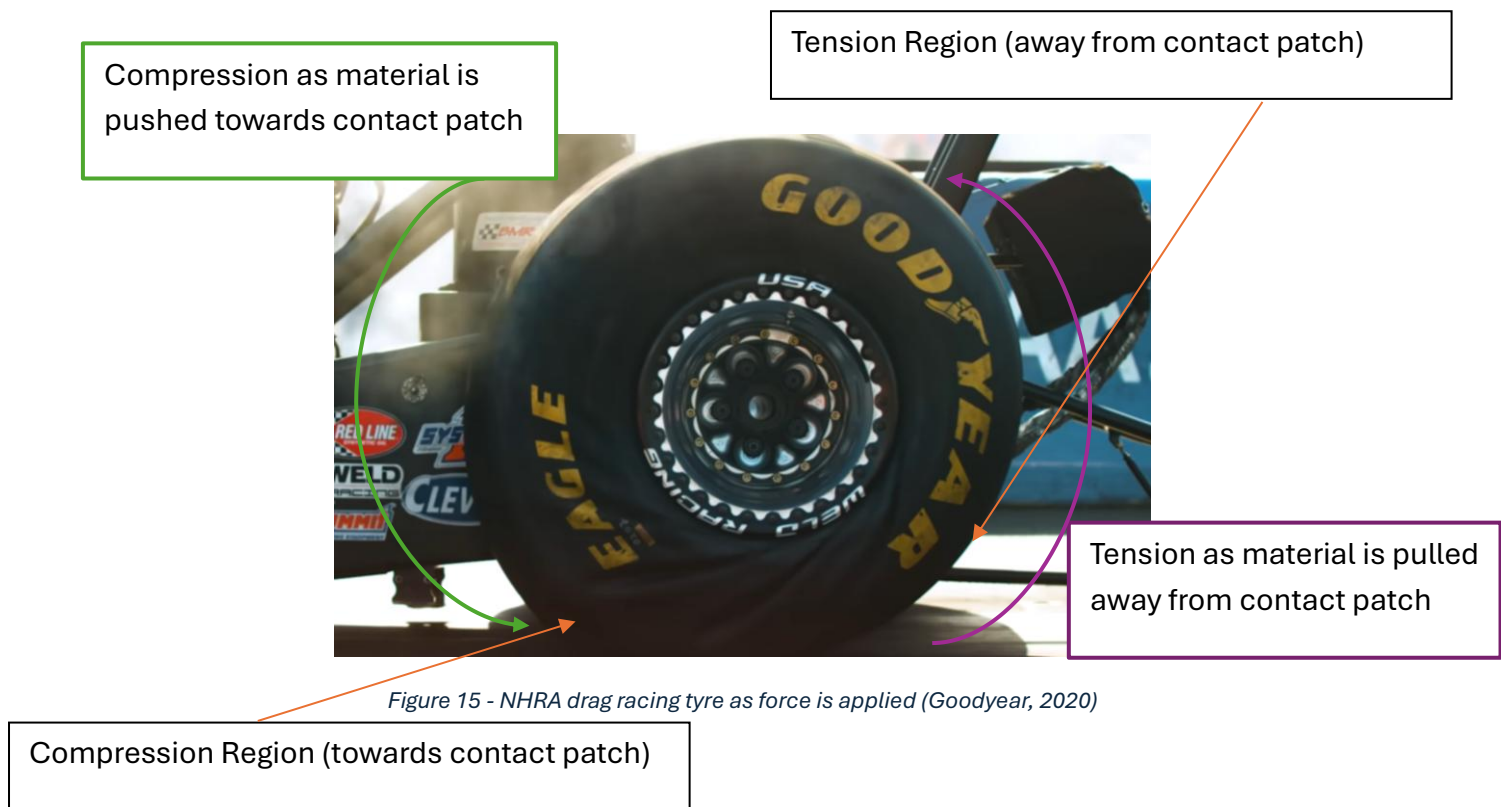
To observe this phenomenon in action, (albeit on a more dramatic scale) please see Figure 14 for an *NHRA drag racing* tyre prior to force application from the drive shaft.

Figure 15 then shows a labelled picture of the tyre as torque from the driveshaft is applied to it. As the material is softer it endures more compression/tension per side, however this effect would still be present to some degree in the driveshaft component, although not visibly. The vehicle in these images move to the left, so the torque is applied in an anticlockwise direction when viewing.

Video available at: <https://www.youtube.com/watch?v=gXp2QgY1OB8>



Figure 14 - NHRA drag racing tyre prior to force application (Goodyear, 2020)



In conclusion, the pattern of the component's cross-sectional area indicates that it failed by fatigue during operation, rather than a sudden impact failure. This is reinforced by the fact that a maximum load of 90MPa was present during the time of failure, which the sample material could withstand. This in addition to the similarity in cross-sectional appearance with the different examples for fatigue failures, more specifically, *torsion-torsion and torsion compression* fatigue failures.

In future, a preventative measure could be addition of service intervals and changing parts when wear occurs. Another potential remedy to improve durability, component life cycle and reduce fatigue rate could be use of a different material that can withstand more stress cycles. Specifying the required grade of material to manufacturers limits the possibility of premature failure due to incorrect grade.

Highlighted previously, the test conducted does not give an accurate view into a product's lifetime. To develop understanding in the future, testing could also include the *Wöhler test*, which provides an S-N curve that indicates a more accurate lifetime of a component under fatigue cycles until fracture. (Roell, n.d.)

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