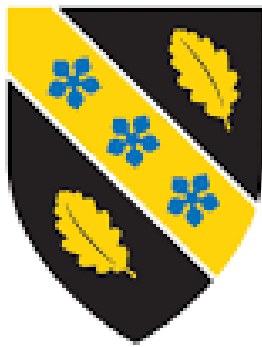


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1. Introduction

The aim of this report is to investigate a suspension failure during a rally by way of a tensile test carried out on a test sample. A recent change to supplier means that the team is confident that the failures are a material issue. The parts were manufactured the exact same way as the old parts supplied by the previous company. The results of the test have been analysed to calculate the yield strength, ultimate tensile strength and Young's modulus. These values will indicate the properties of the material and provide insight into the cause of the failures, ultimately allowing for solutions either to solve the problem or advise measures that will increase the longevity of the component.

2. Literature Review

2.1 Material Properties

During operation the driveshafts experience extreme forces because they transmit torque from the transmission to the wheels, so they have to be strong enough to withstand the stress (Zhao et al., 2019). Alongside the stress, the driveshafts experience a lot of torsional vibrations (from the engine and suspension movement) that can cause failures (Grega et al., 2017). Aluminium composite hybrid driveshafts allow the aluminium to withstand the load and the carbon fibre epoxy increases the natural bending frequency therefore decreasing fatigue from the torsional vibrations (Lee et al., 2004). This reduces the cost by using cheap aluminium to transmit the torque while receiving the advantage of the increased natural bending from the composites (Mutasher, 2009). Mutasher also found that Aluminium has a tensile modulus of around 69 Gpa and a shear modulus of around 26.6 Gpa (2009). Whereas a recent study found that steel had a Youngs modulus value of 196 – 216 Gpa which would mean steel is significantly stronger than aluminium (Chen et al., 2016). The requirements for durability and strength must be met without compromising on the requirements for being lightweight (Zhao et al., 2019). The use of composites target issues such as the vibrations while also being a lightweight alternative. The grain structure in metals has a significant impact on fatigue resistance as it dictates the plasticity properties in the direction of the slip bands (Murakami, 2012). So, the grain size in metals dictates the metal's ability to withstand vibrational and torque without fatiguing or failing. Micro cracks in the grain structure can occur with thermal expansion and may be unnoticed reducing the metals' ability to resist fatigue (Zerbst and Klinger, 2019). This important to note because micro cracks will not be visible to the human eye and can therefore go undetected. They also can happen during the manufacturing process causing weaknesses even before the part has been used. In this case, unless further testing is conducted, there isn't any way of telling if the material the part is made from has any of these micro cracks.

2.2 Testing Methods

2.2.1 Compression Test

In a compression test a material is compressed under load until it either fails or starts to crack. The specimens are standard dimension allowing for each material to be compared equally. A brittle material generally cracks without much bulging and fractures at a 45-degree angle to the force applied. A ductile material will deform and bulge out on the sides. If a material is ductile enough it can crack in the direction the force is being applied. ("Compression test | tec-science," n.d.)

2.2.2 Tensile Test

The tensile test always produces a force-elongation-curve, although "it does not yet allow any statement to be made about the strength of a material". This is because the suspension geometry has a significant impact on a materials ability to withstand stress. Therefore, like in the compression testing a standard dimension must be used. A material has the possibility to go through four stages of strain, the elastic strain, luders, uniform plastic strain and necking

strain. The necking strain is usually seen in ductile materials whereas brittle materials usually snap before leaving the Luders strain. ("Tensile test | tec-science," n.d.)

2.2.3 Fatigue Test

In the fatigue test stress is slowly added to a material. It has a similar set up to the tensile test, although in this case the top clamp oscillates at 200Hz transferring tensile and compressive forces through the material. Simulating the operation on a machine and measuring the materials ability to resist fatigue. ("Fatigue test | tec-science," n.d.)

2.2.4 Stress Relaxation Test

The stress relaxation test measures the stress for a given temperature where a constant amount of strain is present. Creep causes the stress to decrease which gradually leads to tightened parts becoming loose. This is known as relaxation or stress relief. ("Stress-relaxation test | tec-science," n.d.)

3. Methodology

For this investigation the tensile test was chosen as it provides the best data with the sample available.

3.1 The Rig

In order to appropriately inspect the sample provided by the team, a rig was assembled where the tightening of a nut moves the top chuck in order to stretch the sample. The sample was stretched until failure, with the nut turned 2 increments (0.2mm) for every measurement of force taken respectively. One complete turn of the nut equals 1mm of vertical travel and it has ten notches around it. Therefore, the incremental measurement between the notches is 0.1mm of vertical travel of the top chuck and plate. To measure the distance that the sample has stretched there is a plate connected to the top of the top chuck that allows the vertical measuring scale on the side of the rig to record the elongation of the sample. The top plate and scale also allows the nut to be calibrated ensuring that one complete turn does actually equal 1mm of travel.

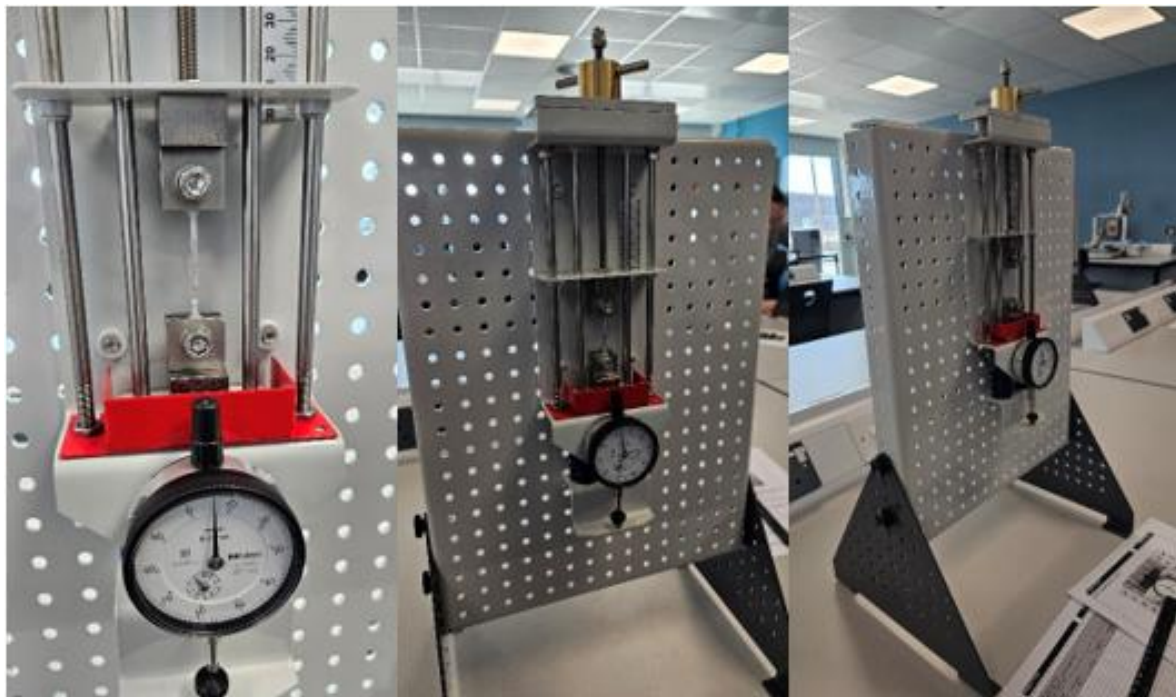


Figure 1 - Test Rig with Sample

The sample was fixed securely on both sides as shown in figure 1. The chuck that the top of the sample attaches to is able to move on the thread up and down respectively. Whereas the chuck that the bottom of the sample attaches to is fixed firmly in place and cannot move. The sample is fitted by unscrewing the fixing that holds it securely in place.

3.2 Dial Indicator

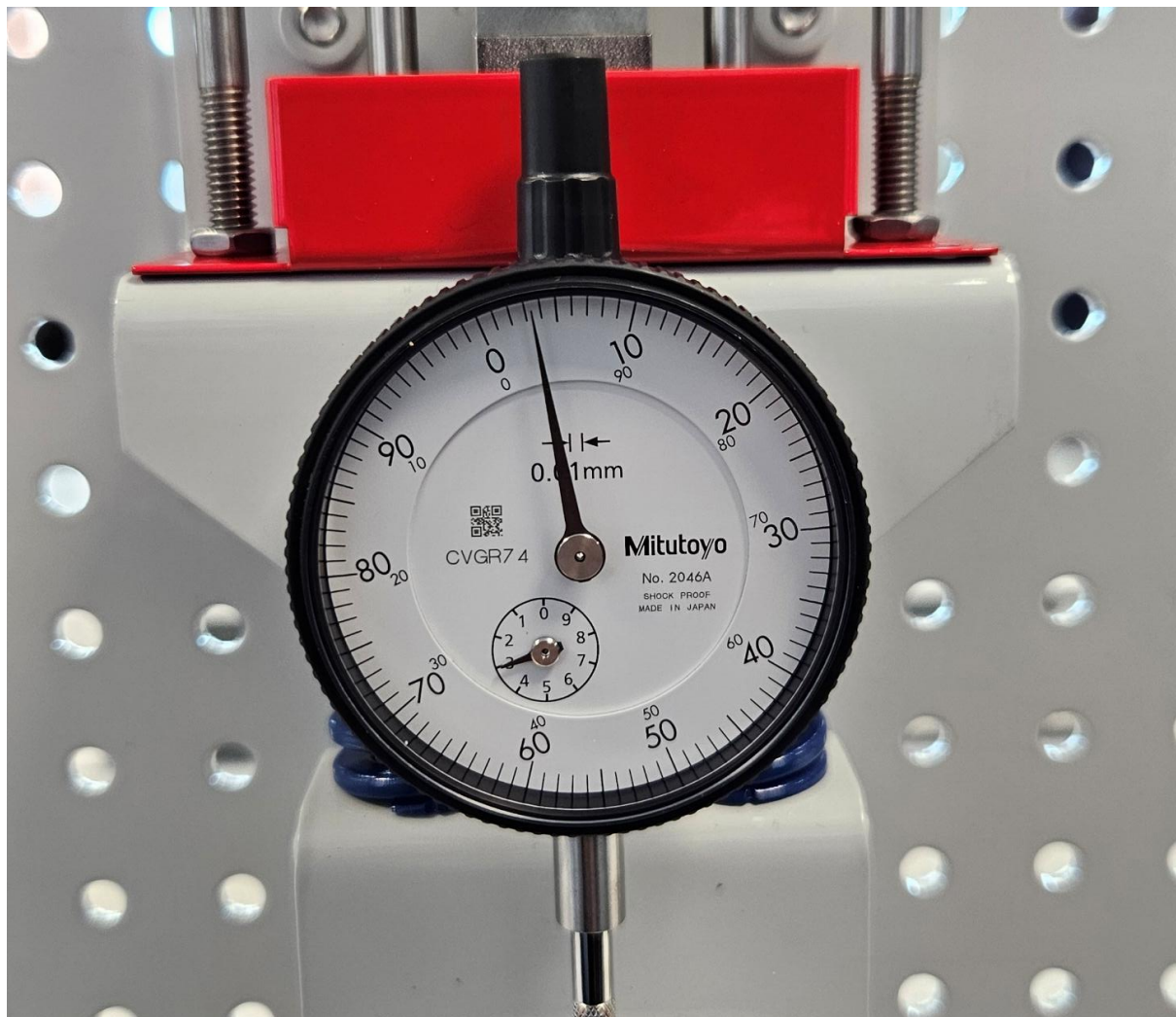


Figure 2 – Dial Indicator

The dial indicator shown in more detail in figure 2, measures the deflection of two springs. These values can be used to calculate the force the sample is under because each increment of measurement on the dial indicator equals 0.01mm of deflection and “the springs have a combined spring rate of 100N/mm (TecQuipment, 2012)” meaning that for 1mm of deflection the sample experiences 100N of force. The measurements from the dial indicator were taken at intervals of 0.2mm of movement for the top chuck. This is an appropriate increment for the measurements to be taken, allowing for the force to display enough data that the results can be scrutinised effectively. Before starting the test, the dial indicator has to be zeroed by rotating the black, outer casing as shown in figure 2. If the indicator is tampered with during the test, meaning that someone accidentally moves the scale, then the test results will be inaccurate, and the test may even need to be restarted. This meant that extra care was taken to ensure that the test was carried out correctly because only one sample was available.

4. Test Results

4.1 Raw Values & Table

The results were imputed into excel as shown in figure 3. The load nut was turned five complete turns and eight notches pausing every 0.2mm to take measurements from the dial indicator. The results from the dial indicator are shown in figure 3 under section dial indicator. The dial indicator showed readings up to 3.52mm until the sample failed at 5.8 turns of the nut.

Load Nut movement (mm)	Dial Indicator (mm)	Force (N)	Extension (mm)	Number of Turns of Force Control (mm)	Stress (σ) N/mm ²	Nominal Strain (ϵ)
0	0	0	0	0	0.0	0.0000
0.2	0.13	13	0.07	2	6.5	0.0023
0.4	0.28	28	0.12	4	14.0	0.0039
0.6	0.46	46	0.14	6	23.0	0.0045
0.8	0.64	64	0.16	8	32.0	0.0052
1	0.83	83	0.17	10	41.5	0.0055
1.2	1.01	101	0.19	12	50.5	0.0061
1.4	1.182	118.2	0.218	14	59.1	0.0070
1.6	1.33	133	0.27	16	66.5	0.0087
1.8	1.52	152	0.28	18	76.0	0.0090
2	1.7	170	0.3	20	85.0	0.0097
2.2	1.87	187	0.33	22	93.5	0.0106
2.4	2.04	204	0.36	24	102.0	0.0116
2.6	2.2	220	0.4	26	110.0	0.0129
2.8	2.37	237	0.43	28	118.5	0.0139
3	2.55	255	0.45	30	127.5	0.0145
3.2	2.7	270	0.5	32	135.0	0.0161
3.4	2.81	281	0.59	34	140.5	0.0190
3.6	2.95	295	0.65	36	147.5	0.0210
3.8	3.02	302	0.78	38	151.0	0.0252
4	3.12	312	0.88	40	156.0	0.0284
4.2	3.21	321	0.99	42	160.5	0.0319
4.4	3.28	328	1.12	44	164.0	0.0361
4.6	3.35	335	1.25	46	167.5	0.0403
4.8	3.4	340	1.4	48	170.0	0.0452
5	3.42	342	1.58	50	171.0	0.0510
5.2	3.45	345	1.75	52	172.5	0.0565
5.4	3.52	352	1.88	54	176.0	0.0606
5.6	3.52	352	2.08	56	176.0	0.0671
5.8	broken			58		

Figure 3 - Results Table with Calculated values

The dimensions of the sample are shown in figure 4, with a gauge length of 31mm and a cross-sectional area of 2mm squared.

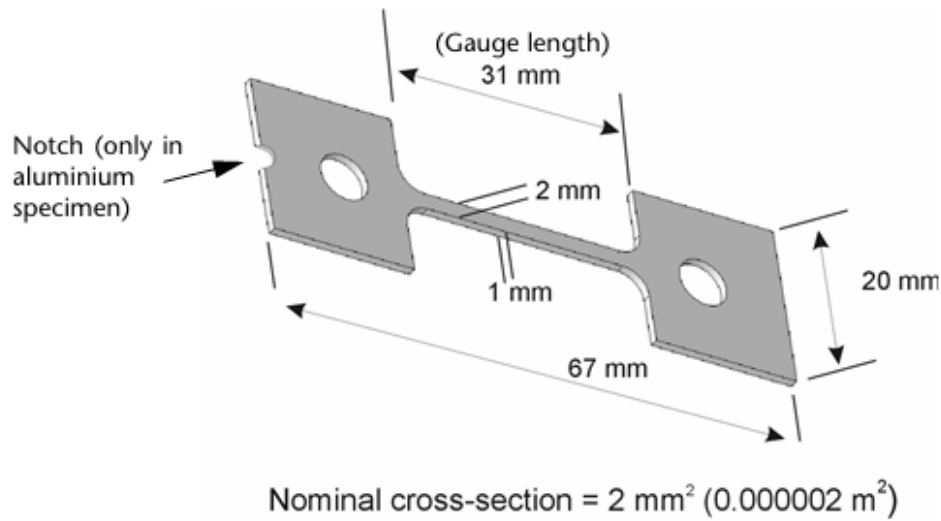


Figure 4 - Sample Dimensions (TecQuipment, 2012)

4.2 Calculated values

4.2.1 Force

The force acting on the sample was calculated, knowing that the springs have a spring rate of 100N/mm, using the following formula:

$$100 = \frac{F}{L}$$

Equation 1 - Force Formula

Which can be rearranged to find the force (F):

$$F = L \times 100$$

Equation 2 - Rearranged Force Formula

Therefore, the sample withstood a maximum force of 352N before eventually breaking.

4.2.2 Extension

The elongation was calculated by subtracting the amount of movement of the top chuck and plate by the reading on the dial indicator respectively. This gave a final extension value of 2.08mm. This is shown in figure 5 where a tested sample is compared with a sample that hasn't been tested, it is clear that the tested sample has changed in length. Visually it looks like the sample has been stretched a couple of millimetres, confirming that the value found for final extension is correct. This happens because the material plastically deforms before breaking.



Figure 5 - Tested Sample vs Untested Sample

5. Analysis

From the results presented in section 4 a stress strain graph could be plotted. These graphs are vital to understanding and scrutinising the properties of a material. On the graph there are two sections the elastic region and the plastic region. The elastic region of the graph is the linear or first part of the graph, the plastic region is when the stress starts to level off (when the material permanently deforms). This graph allows for yield strength, ultimate tensile strength and Youngs modulus to be found which will provide insight into the materials properties. The material withstood a significant amount.

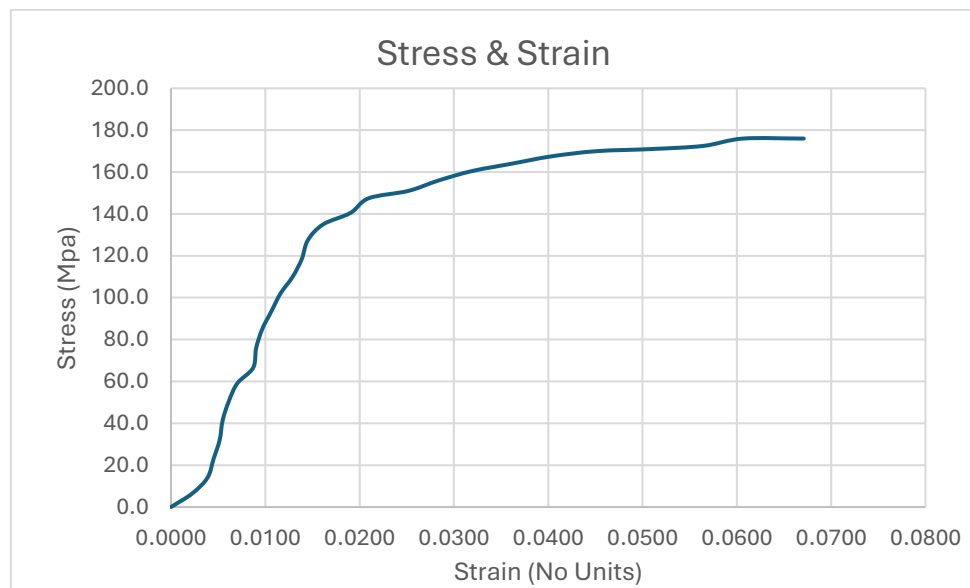


Figure 6 - Graph Showing Stress and Strain

5.1 Yield Strength

The yield strength is found at the end of the elastic (Linear) region of the graph and just before the material starts to permanently deform and enter into the plastic region. For this sample tested the yield strength was found at 151.00 Mpa; showing that the material selected by the manufacturer contains the appropriate amount of strength required for the component to operate effectively while remaining in the elastic region, preventing the part from permanently deforming.

5.2 Ultimate Tensile Strength

The maximum stress shows when a part will completely fail. Therefore, the last measurement taken before the sample failed is the ultimate tensile strength, which was found to be 176 Mpa. This is much higher than the amount of stress measured on the component during the race, which was 90 Mpa. Indicating that the material has a sufficient strength to cope with the stress present during operation without failing.

5.3 Youngs Modulus

To calculate the Youngs modulus the value of the gradient can be taken because Youngs modulus is stress divided by strain. From the gradient shown in figure 7 the Youngs modulus can be taken as 72.6Gpa. The Youngs modulus gives an indication for how stiff a material is. Aluminium is one of the softer metals available meaning that it will provide a lower Youngs modulus to that of steel.

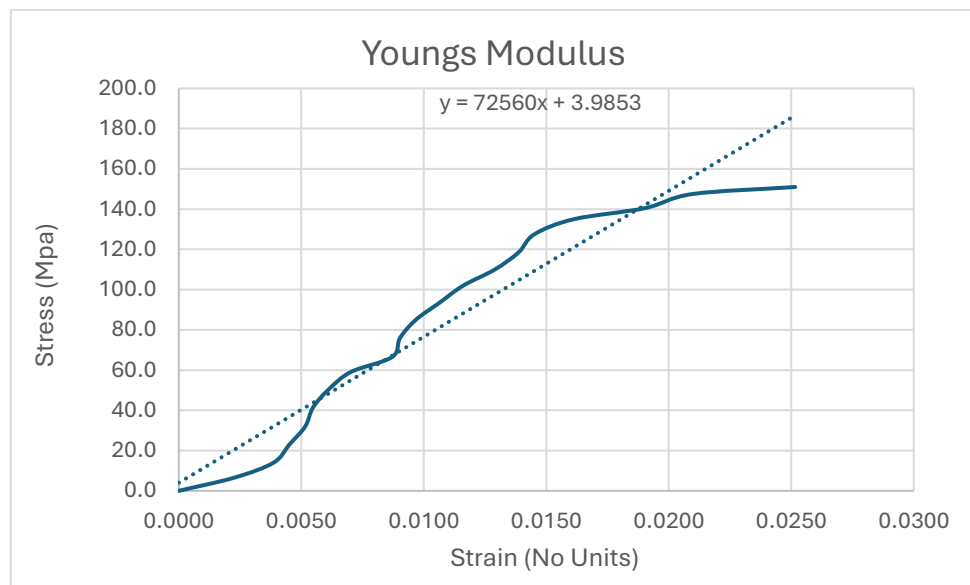


Figure 7 - Stress vs Strain (Elastic Region only)

6. Conclusion

In conclusion the material chosen seems to have all the suitable characteristics that would enable the component to operate effectively under the given conditions. However, the cause of the failure was definitely fatigue. In the figure below there are clear striations at the bottom of the photo. If there was some sort of weakness created in the material through stress concentrators such as chips or damage to the part, then the material becomes significantly weaker. To prevent this happening in future a visual inspection should be conducted at regular intervals to ensure that the part isn't damaged in anyway. Through vibrations and torque being transmitted the striations would have grown larger and larger until the part became weak enough that it would have broken. From the analysis it is clear that the part was strong enough to withstand significant tensile stress however if a stress concentrator caused the force to overload in one part of the component, then it is feasible that the stress could have exceeded the yield strength and plastically deformed. Once a part plastically deforms it does not return to its original shape. Therefore, continued use of the component and continuous torque being transmitted through the part would have continued to deform the part and enlarge the striations. Further research should be conducted to investigate if it would be worth changing these components at an appropriate interval that would prevent and stop the component failing and causing retirements during the races.



Figure 8 – Failed Component

Other solutions could be to incorporate composites into the design, so the torsional vibrational forces have less impact on the aluminium. This would be a costly way of preventing any further failures in the future however it would reduce any possible way that torsional vibrations could impact the striations. Although this is not a direct cause of the failure it may increase the longevity of the part.

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