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Accelerated Fatigue Life Estimation of An Axle Housing

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Research Article

Abstract

In this study, the fatigue test time of an axle housing was aimed to decrease by increasing the testing load without having permanent deformation on the housing. In this concern, the deformation values of the banjo zone of a heavy-duty commercial vehicle welded complete axle housing under static loads were measured with a dial indicator, the elastic behavior of the housing was observed, and the yield limit was tried to be determined. The axle housing underwent vertical fatigue tests under specified elastic loading circumstances, and the housing's fatigue life was examined under progressively higher loading conditions. In parallel with the static and fatigue tests, the stress and displacement values in the axle housing were obtained with the finite element analysis program ANSYS and verified with the test results. Load conditions, test configurations and fatigue life results are described in detail in the article. Considering the preliminary study [1] results, this study went one step further and tried to obtain the optimum load-life relationship that can be applied as accelerated vertical fatigue test condition for verification of an axle housing. In this way, it is aimed to reduce the time spent on fatigue tests and to provide economic benefits by performing tests in fewer cycles with a higher load.

Keywords: Accelerated fatigue life; Axle housing; Elasticity; Finite element analysis; S-N curve; Strain; Stress; Yield

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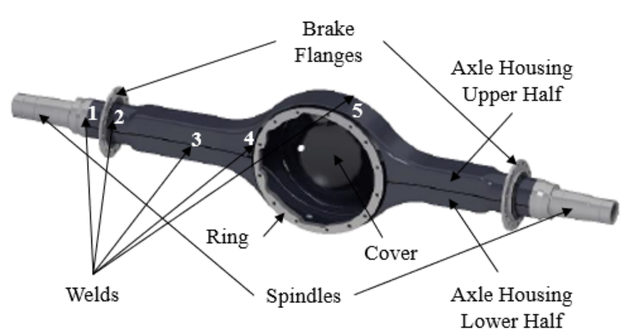
1. Introduction

Releasing innovative and economic products into the markets in reduced time compared to other rivals always forces Original Equipment Manufacturers (OEMs) and suppliers to improve their methods and technologies. These improvements aim to develop competitive products in terms of lightweight, low cost, strength and guarantee non failure in the service life. Experimental testing must be completed before the product's ultimate release to avoid any kind of unanticipated failure in the product's life. However, the road tests are very expensive and long-lasting since they reflect the real time condition and use complete vehicles. In order to reach economic and safety goals, the need for accelerated tests is urged to evaluate the components durability with different design proposals in relatively much shorter time [2].



Welding areas and their types in an axle housing between sub-parts:
1. Frictional stir weld between spindles and housing halves
2. Tee arc weld between brake flanges and housing halves
3. Seam arc weld between axle housing upper and lower halves
4. Tee arc weld between ring and housing halves
5. Corner arc weld between cover and housing halves

Figure 1. A heavy-duty commercial vehicle fabricated axle housing, sub parts and their welding types

As described in the previous article [1], the purpose of an axle housing (Figure 1), a safety element beneath vehicles, is to support gross axle weight ratings (GAWR) and house differential gear systems. The axle housing of a heavy-duty vehicle is expected to withstand static and dynamic loads generated by the rough road conditions until the vehicle's operational life is over. Therefore, the manufacturers simulate and validate those conditions using several methods such as finite analysis during design and fatigue testing after manufacturing stages. [3]

The most popular technique for connecting two metals is welding. Because the components and the weld fuse together, it offers high adherence to the product. Since the axle housing is made of metal, the pieces are assembled via friction stir welding and arc welding. The welding areas and common welding types used in axle housing are shown in Figure 1. There are 5 basic sub-parts of axle housing; spindles, brake flanges, axle housing halves, ring and cover. As seen from Figure 1, these sub-parts are connected to each other with chosen different types of welding. The reason behind this is to maximize strength in connections and minimize the cost, in boundaries of manufacturing. Arc welding is used in most of the connections for its practical application and lower cost. However, for spindle connection with the housing frictional weld is chosen since spindle has crucial role in carrying the side loading during cornering of the vehicle and its round shape makes frictional weld possible. As well as the benefits, welding weakens materials because of high usage of heating during the operation. Furthermore, under static and/or dynamic loading, the strength of the structure is influenced by the weld's hardness and surface roughness. Because of this, the connection areas are the most important and fragile regions for the housing to fail.

It is possible to evaluate the impact of welding on the product prior to manufacturing by employing a few pricy simulation technologies. However, the manufacturing imperfections cannot be included and foreseen in those analysis. To consider and see the welding and manufacturing effects, usually bench fatigue tests are conducted for finished product validation. The product is mounted on the bench to simulate under vehicle circumstances and the load is applied until the failure occurs. At this point, the handicap of the bench test arises since the tests take a long time to accomplish. Even though the bench test is shorter than the real road tests, still a vertical fatigue life bench test runs averaged for 5-6 days (24 hours/3shifts per day).

It is objected to shortening the testing period in this study. Even a slight reduction in test duration would have a significant impact on overall validation time and cost savings when taking into account the validation number of samples and the elapsed until the results are achieved. Among other strategies [4], increasing the product load used in fatigue bench testing is one of the best ways to shorten test times.

For this purpose, a static displacement test was conducted to define the load limits of the axle housing without exceeding the elastic limits. After that, the high loaded vertical fatigue tests were proceeded within the load limits and the graph of S-N curve was obtained for the welded complete axle housing.

2. Static Displacement Test

As a first step of the study, the static displacement test was carried out for sample axle housing. The aim of the static displacement test was to define the elastic limit of the structure. The elastic limit is the domain in which a body regains its prior position or shape after removing stress causing the deformation [5].

The most significant diagram for mechanical properties is the stress-strain curve. This curve shows the relationship between applied force and how much a material moves accordingly. Hooke's law is applicable in the straight-line segment of the stress-strain curve, which is known as the elastic regime. It is possible to recover the deformation in the elastic regime. Following the elastic regime, the material passes to elastic + plastic regime where it cannot fully recover its deformation and permanently yields. As shown in Figure 2, the proportional limit P is the boundary between the elastic and elastic + plastic regimes and the yield strength σ_y is determined using 0.2% strain offset method that covers the deviation from straight proportionality line.

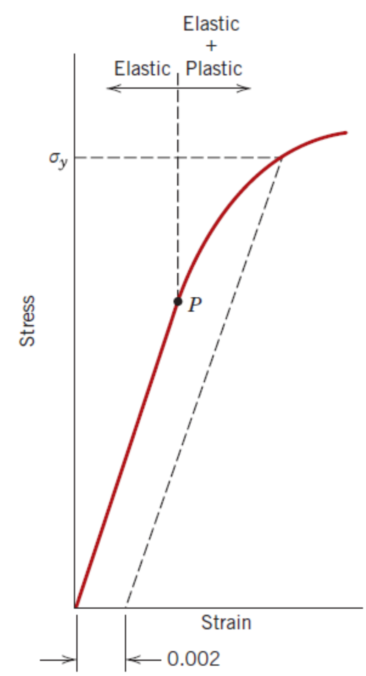


Figure 2. Stress–strain behavior for a metal showing elastic and plastic deformations

By this experiment, the approximate load limit is aimed to be defined by starting with low load level and increasing up to high value where elastic behavior turns into plastic behavior. This limit is called the yield point where yield or plastic deformation starts for the body [6]. In the test, axle housing deflections were measured at each load increments for loaded and preloaded conditions. When the deviation of 0.2% is exceeded, the plastic deformation starts, and it increases with the load increase.

The deformation of the axle housing was measured with a dial indicator and recorded. It is expected that the above Hooke's Law will apply for the axle housing and there will be no permanent deflection in the elastic zone and there will be plastic deflection after elastic limit. Thus, the deflection difference between loaded and unloaded situations were calculated and the point the difference exceeds the 0.2% of the strain was marked as the yield point of the body.

2.1 Application of the Static Displacement Test

The axle housing was mounted on the test stand in vehicle design position. Figure 3 shows the test setup.

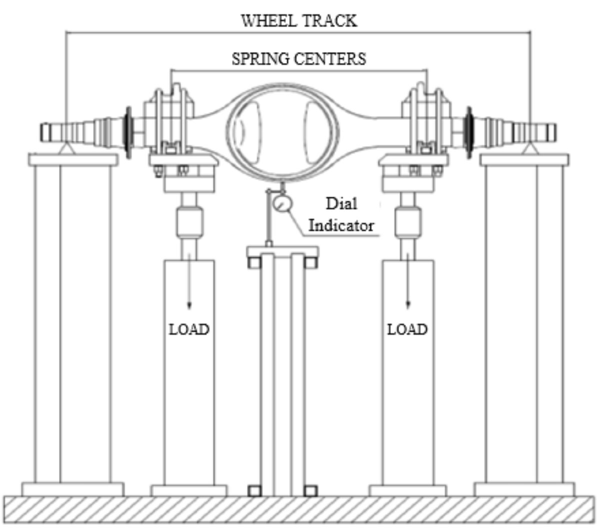


Figure 3. No permanent and permanent deformation of a paper clip

A pre-test break in was performed as follows;

- The load amplitude was set to 0 - 1G (0.5G per spring seat where G is the gross axle weight rate-GAWR)
- 500 cycles were completed at the specified load.

A dial indicator was placed at the lower center of the axle banjo zone (max. deflected area) as seen in Figure 4 below:

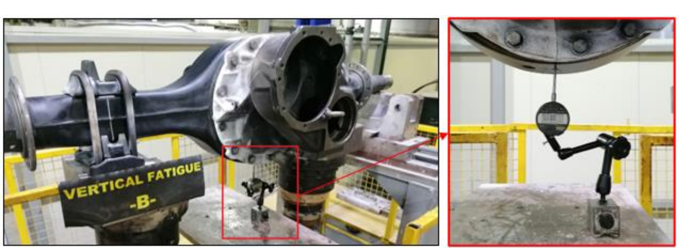


Figure 4. Static displacement measurement with dial indicator

The preload amplitude was adjusted to obtain a static 5% G axle load. And the dial indicator was set to 0 at preloaded position. Finally, static test loads were applied at the following intervals, reading were taken and recorded from the dial indicator clock as follows:

1. The load was increased in predetermined increments.
2. Measurements on dial indicator were read and recorded.
3. Then the load was returned to zero point.
4. Measurements on dial indicator were read and recorded.
5. Steps 1. thru 5. were repeated for 0.5, 1.0, 1.5, 2.0, 2.2, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9 and 4.0G static loads.

2.2 Results of the Static Displacement Test

Static displacement test was performed, and the measurements were recorded as in Table 1 below:

Table 1. Static displacement test results

Max. Load [G]	Preload [G]	Displ. at Max. Load [mm]	Displ. at Min. (Preload) Load [mm]
0,5	0.05	1.28	0.072
1,0	0.05	2.94	0.190
1,5	0.05	4.62	0.220
2,0	0.05	6.32	0.270
2,2	0.05	6.94	0.225
2,4	0.05	7.63	0.270
2,5	0.05	7.95	0.245
2,6	0.05	8.30	0.250
2,7	0.05	8.64	0.270
2,8	0.05	8.98	0.300
2,9	0.05	9.32	0.306
3,0	0.05	9.66	0.350
3,1	0.05	10.00	0.400
3,2	0.05	10.40	0.510
3,3	0.05	10.80	0.550
3,4	0.05	11.17	0.650
3,5	0.05	11.50	0.570
3,6	0.05	11.88	0.700
3,7	0.05	12.00	0.720
3,8	0.05	12.65	0.960
3,9	0.05	13.01	1.200
4,0	0.05	13.60	1.750

As seen from the above measurements in maximum deflection area of the axle housing, which is bowl area, deflections are increasing in parallel with increasing loads starting from 0.5G to 4.0G. Every material has a relation to load (i.e. stress) and corresponding displacement (i.e. strain). With assumption of the axle housing as a united product, the stress-strain curve was created using these measured displacements and corresponding applied load data, as seen in Figure 5 below:

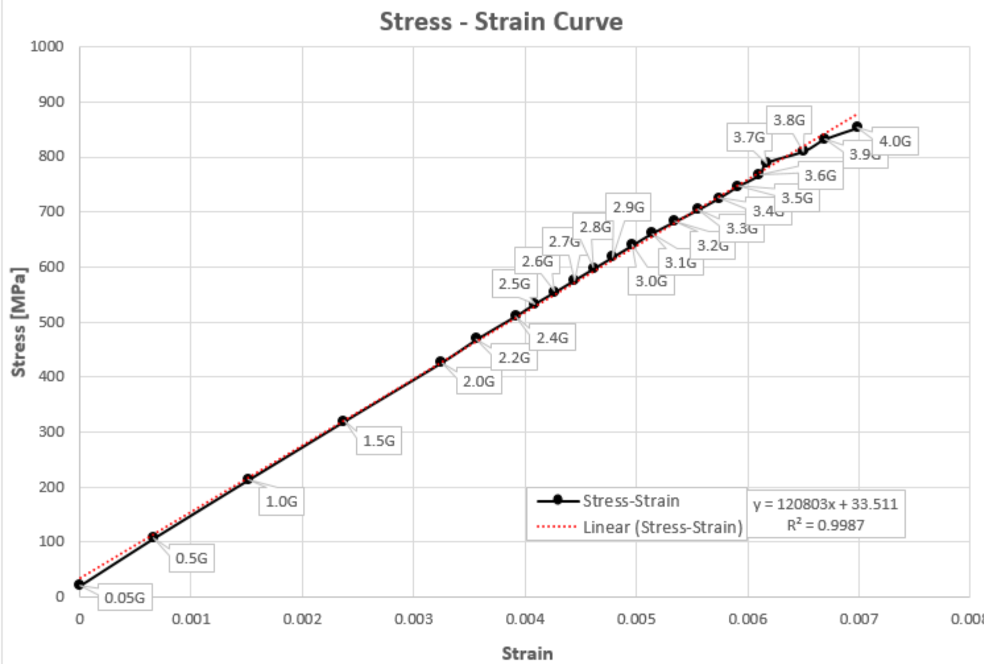


Figure 5. Stress-strain curve obtained by static deflection test

According to the stress-strain graph above, it is seen that the housing is returning to its original position (with small deviations) when the load removed (only preload applied) up to 3.6G loading. These deviations increase after this point. The elastic limit of the housing can be taken as 3.6G, however the housing is a complex product having numerous welding connections between sub-parts. In the following section, the estimated elastic limit will be defined for FEA and fatigue testing.

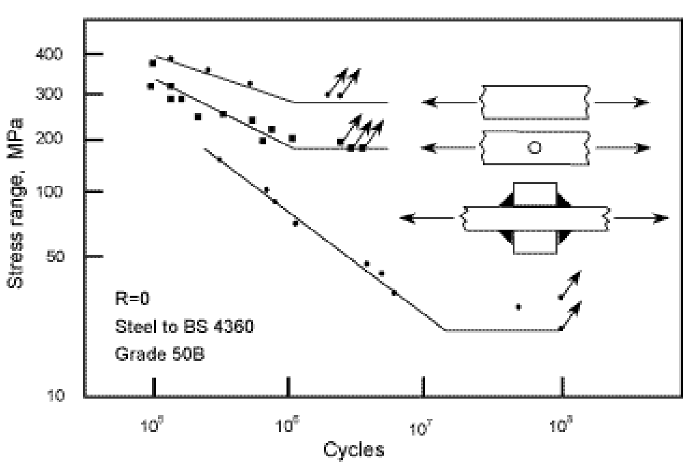


Figure 6. Fatigue strength of base, perforated and welded structure

2.3 Evaluation of the Static Displacement Test Results

Welding imperfections and flaws, residual stress, local and global stress concentrations are the main causes of decreased fatigue strength in welded structures. Early fracture initiation will be caused by the localized stress concentration combined with flaws, and crack growth will dominate the weld fatigue [7]. Figure 6 below shows how the weld forms and joint geometry, weld defects, high tensile residual stresses, and other factors reduce the fatigue strength of welded structures as compared to base and perforated base material:

The axle housing investigated has bores at ring connection and welds between all the components. Therefore, the fatigue life of the complete structure will be much more below than the single structures that it consisted of.

According to the stress-strain curve above Figure 6, the housing is returning to its original position up to 3.6G loading without major deviation.

Nevertheless, in light of the fatigue behavior of welded structures explained above, the acceleration fatigue life study will be conducted up to 3G loading instead of 3.6G, making sure that the welded structure will not be overloaded in the welds and will not cause any permanent deformation until the axle housing cracks.

In addition, as a result of previous tests, it has been observed that excessive loading results in the contacts between the test fixtures and the axle housing getting closer especially at the spring seat and cylindrical support regions and causes unrealistic cracks, which overshadows the observability of crack formation in the expected areas. For these reasons, the tests will be carried out up to the limit value that the real conditions allow, without focusing only on the elastic limit.

3. Finite Element Analysis

This axle housing is actively used under one of the commercial trucks. The static loading that applied during the design stage is defined by the customer and written in their specifications. The endurance of the parts and connections are simulated with an FEA commercial program. By this study, the weakness and robustness of the assembly can be predefined. After that, dynamic durability is checked by fatigue bench tests of the housing. The loads are adjusted to simulate behavior of the axle housing under the vehicle. The defined load is higher than the load that vehicle encounters during its life otherwise the fatigue test would continue for years until failure on the parts. Even if the load is amplified by the customer, still the fatigue bench test lasts for days and even weeks. That means high validation cost for the customer. In the competitive automotive industry, reducing testing time and saving money is highly essential to serve goods fast and cheaper. To decrease testing time, in this study the load will be increased to a proper level. For this purpose, first all the tools used in simulation and validation are checked for compatibility to measure weak spots of the axle housing. Details of this prior study are published as [1]. According to the study, data acquisition (DAQ), validation (fatigue test bench), and simulation (FEA) methods were used to explore and experimentally examine the effects of changing loading circumstances on the fatigue life of the axle housing and stress concentration locations [8]. According to the study, the data acquired from strain gauges validate FEA results. Moreover, FEA and the bench testing results are quite compatible.

With the confidence of previous study [1], a similar FEA study was performed to simplified deformation model that reflects housing's free body diagram under vehicle and the effect of the load increase on the stresses at the housing's critical regions were observed.

- The product was modeled using CATIA (V5 R18), a commercial 3D CAD program
- The 3D model was imported into FEA software program, ANSYS Mechanical Workbench (2022 R1).
- The analysis model was fine meshed around the stress concentrated areas, critical sub parts and load application regions. Other components were relatively coarse meshed for optimum solving time. The mesh density can be seen below Figure 7. In meshing;
  - Tetrahedron (tet10) type of elements used since they fit better complex geometry (470.431 elements with 942.082 nodes) with
  - Element sizes of; axle housing halves: 6mm, welds: 4mm, ring: 8mm, spindle: 8mm, cover: 8mm, brake flanges: 8mm, seats: 8mm were used.

Figure 7. FEA model mesh density

- To imitate vehicle riding conditions, the load application and support conditions were adjusted as follows (Figure 8):
  - Cylindrical supports were placed at the track widths to allow the axle housing to be attached in axial and radial directions but free in tangential directions.
  - The load gradually increased, beginning with GAWR, at the axle seats downwards (-z).

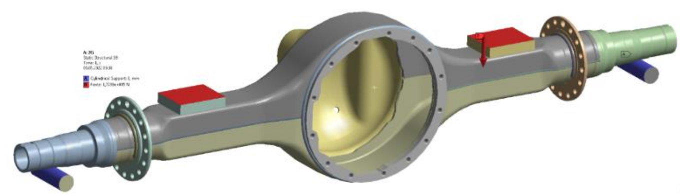


Figure 8. Load application and FBD of the FEA model

- The sub-parts material mechanical properties that were obtained from experimental studies were implemented into ANSYS library
- Based on the findings of the structural analysis, the highest stress zone was defined as the lower banjo ring weld region. The location (red mark) can be seen in the below Figure 9:

Figure 9. FEA stress results display for 2G loading, max. principal stress

FEA runs for all defined load increments were performed and the max. principal stress results for the ring weld area were listed below Table 2:

Table 2. Max. principal stresses related loads

Load [G/piston]	Load [kg/piston]	Max. Principal at Ring Weld Area [MPa]
1.00	9,072	426.69
1.10	9,979	469.36
1.20	10,886	512.03
1.25	11,340	533.36
1.30	11,794	554.47
1.35	12,247	576.03
1.40	12,701	597.37
1.45	13,154	618.70
1.50	13,608	640.04

It is observed that stress linearly increases as the load increases. As long as preserving elastic behavior of the body, fatigue life would decrease as proportional with increase of the applied stress. To observe this relation between stress increase and fatigue life decrease, a number of fatigue bench tests were performed with the above loads.

4. Vertical Fatigue Test

Fatigue is the most frequent cause of mechanical structures breakdowns. Structures fail when subjected to a repeated load even when the load is well below the static material strength. After prolonged and repeated loading, a part eventually fails in three steps:

- A small amount of damage develops at the microscopic level and worsens with a large amount of cyclical loading until a macroscopic crack forms.
- The macroscopic crack that has already formed propagates with each cycle until it reaches a critical length that will compromise the integrity of the structure [9].
- When the cracked component can no longer withstand the peak load, it breaks.

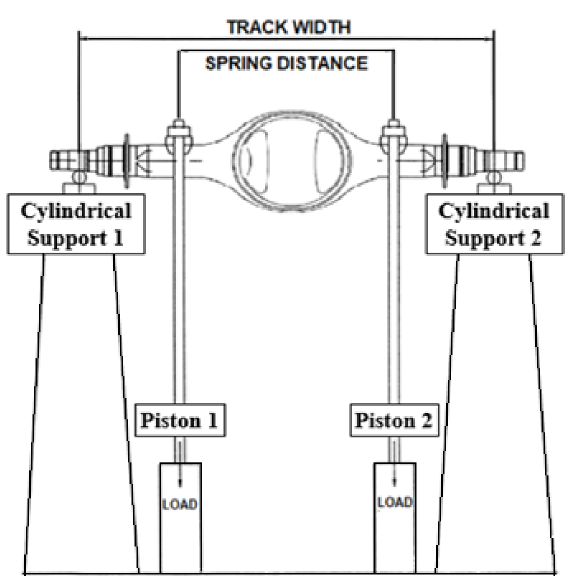


Figure 10. Front view of test set-up simulating road conditions

In other words, there are three stages to a structure's fatigue life: crack initiation, crack propagation, and fracture. In this study, the first and second stages of fatigue life will be investigated since the axle housing is a safety component under the vehicle, and it has a limit of crack growth. When this length is achieved, the test is stopped. However, in some cases, the cracks were propagated very rapidly without recording the tolerated length and the cracked components had broken.

As the equipment, MTS 400kN actuators with ±250mm stroke performed the fatigue bench tests. Axle housings were mounted on the test stand in vehicle design position with:

- Cylindrical supports at the track width (to represent wheel hub connection)
  - Track width: 1945.6mm
- Actuators at the spring seats (to transfer vehicle load on the axle)
  - Spring distance: 1028.7mm
  - The set-up configuration can be seen in Figure 10 [1]:

A sample axle housing set-up at the test rig can be seen in Figure 11 below:

Figure 11. Test set-up front view of an axle housing

- The housings used in the experiments were manufactured with the same design and production parameters, in the same line and at the same working shift. These identical samples enable us to conduct a controlled experiment.
- Each set up was prepared by applying the proper torque value to fix the spring seats with the hosing and the pistons. Also, the touch points of the spindles on the cylindrical supports were greased to minimize the friction to represent vehicle riding conditions.
- The test was carried out for a number of axle housings. The loadings were established based on the housing's capacity to support loads and the limit of structural flexibility [10].
- The loads ranged from 2G (default testing condition) to 3G (a load in elastic zone).
- In each load step, 3 housings were tested to validate fatigue behavior under the changed loads

The fatigue tests were conducted with the following peak (max.) and preloads (min.). (Table.3).

Table 3. Loading for each housing set

Peak Load		Preload	
[G/piston]	[kg/piston]	[G/piston]	[kg/piston]
1.00	9,072	0.05	454
1.10	9,979	0.05	454
1.20	10,886	0.05	454
1.25	11,340	0.05	454
1.30	11,794	0.05	454
1.35	12,247	0.05	454
1.40	12,701	0.05	454
1.45	13,154	0.05	454
1.50	13,608	0.05	454

- Sinusoidal load was applied to the housing with the loads between peak (σ_{max}) and preloads (σ_{min}). A cycle is the time passing between two-peak stresses. The test load vs. time graph can be seen in the figure below (Figure 12):

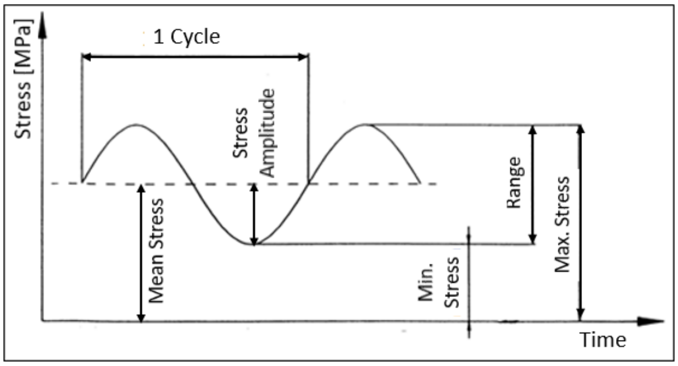


Figure 12. Typical sinusoidal test loading, load range and cycle

- The arithmetic mean of the highest and minimum stresses is known as the mean stress (σ_m). Eq. (1) and (2) define the alternating stress (σ_a), commonly referred to as the stress amplitude, as the difference between the peak and mean stresses [11]:

$$\sigma_m = ½\,(\sigma_{max} + \sigma_{min}) \quad (1)$$

$$\sigma_a = ½\,(\sigma_{max} - \sigma_{min}) \quad (2)$$

- The ratio of the minimum cyclic stress to the maximum cyclic stress is known as the stress ratio (R). R=-1 for a fully reversed loading where min. and max. stresses are reverse but have equal magnitude. R=0 for the loading is applied and removed (not reversed) case. In this study, the fatigue test and the FEA analysis were performed with a constant amplitude load ratio of R=0.05G (preload). Ratio based load application graph of the study can be seen in the below (Figure 13):

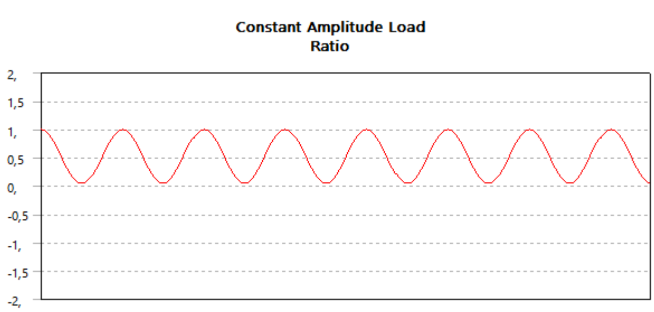


Figure 13. Ratio based sinusoidal load application, R=0,05G

- The tests were checked periodically for any crack initiation and formed crack growths were followed by noting down the corresponding cycles.
- All these test results were collected to graph a fatigue S-N curve of the structure.

5. Results

5.1. Fatigue Bench Test Results Data

For every load increment, 3 specimens were tested and the results of these tests with the testing parameters are displayed in the following Table.4 and for better understanding the crack locations are labeled in (Figure 14).

Table 4. Fatigue bench tests results

Test No	Total Load [G]	Test Time [Day]	Crack Initiation Cycle	Propagation Limit Cycle	Cracks Locations (Figure 14)	Cracks Lengths
1	2,0	4.5	558,500	785,100	6	85 mm
2	2,0	7.6	684,900	1,313,601	5 6 2	45 mm 50 mm 210 mm
3	2,0	5,2	881,300	893,500	6	80 mm
4	2,2	4.3	485,900	744,220	6	77 mm
5	2,2	4.9	632,350	851,680	6 2	50 mm 150 mm
6	2,2	3.3	511.750	564.650	6	76 mm
7	2,4	3.0	387,300	526,000	6	78 mm
8	2,4	2.7	328,000	466,920	6	80 mm
9	2,4	3.6	338,400	623,100	6	80 mm
10	2,5	3.1	398,100	539,900	6	90 mm
11	2,5	2.8	306,000	455,813	6 5	110 mm 25 mm
12	2,5	3.0	331,550	512,600	6	90 mm
13	2,6	2.3	297,300	392,000	6	76 mm
14	2,6	2.7	311,200	472,000	6	80 mm
15	2,6	2.4	205,000	408,610	6	77 mm
16	2,7	2.4	305,000	419,500	6	76 mm
17	2,7	1.7	178,500	295,600	6	85 mm
18	2,7	1.6	199,000	275,300	6	80 mm
19	2,8	2.0	271,000	349,600	6 2	40 mm 200 mm
20	2,8	2.2	253,500	378,700	6	79 mm
21	2,8	1.7	191,500	289,300	6	77 mm
22	2,9	2.1	275,100	367,100	6	78 mm
23	2,9	1.3	200,000	230,400	6 11	40 mm 130 mm
24	2,9	2.1	209,500	361,600	6 2	60 mm 190 mm
25	3,0	1.6	230,400	270,900	6	80 mm
26	3,0	1.4	191,700	245,272	6 11	70 mm 120 mm
27	3,0	1.9	265,000	335,700	5 2	35 mm 200 mm

Figure 14. Crack locations

It is observed that the results are very compatible both for the crack initiation regions and the cycles. Also, the main objective of reducing testing time is obtained by decreasing fatigue life with increasing applied load. With basic knowledge of fatigue phenomenon, it is easy to predict that fatigue life of a metallic component decreases with increasing load [12]. So, as expected, the above study proved this prediction as in many studies in literature. Moreover, this study differs from the others since it comprehends the accelerated fatigue test of whole axle housing with welded sub-components on a bench [2].

Also, it can be seen that the failure regions are changing with the load increase, as mentioned in section 2.3. With the increase of the load at pistons, the connection between spring seat and the housing is getting closer and even touching each other which easily results in early crack initiation by notch effect [13]. In section 6, these failures will be interpreted

5.2. S-N Curves

Approximately 90% of mechanical failures in metallic structural components are attributed to fatigue failure, one of the primary failure modes in engineered materials [14]. Therefore, it is crucial to assess and forecast the fatigue properties of metallic materials. Wöhler presented the fatigue analysis using the stress-life technique, which is represented by an S-N curve in Figure 15. The S-N curve is widely used, especially for determining high-cycle fatigue [15]. High cycle fatigue, defined as 104 cycles or more, indicates that the deformation is within the elastic range and the stress level is relatively moderate. The nominal stress against the number of cycles to failure curve, which is provided with data from a series of fatigue tests, is known as the S-N curve for a particular material or structure. Plotting is typically done on a semi-log scale, with a logarithmic scale applied to the number of cycles. Because N values typically fall within a wide range, this has the effect of linearizing the plot and greatly simplifying the visualization of the correctness of the model.

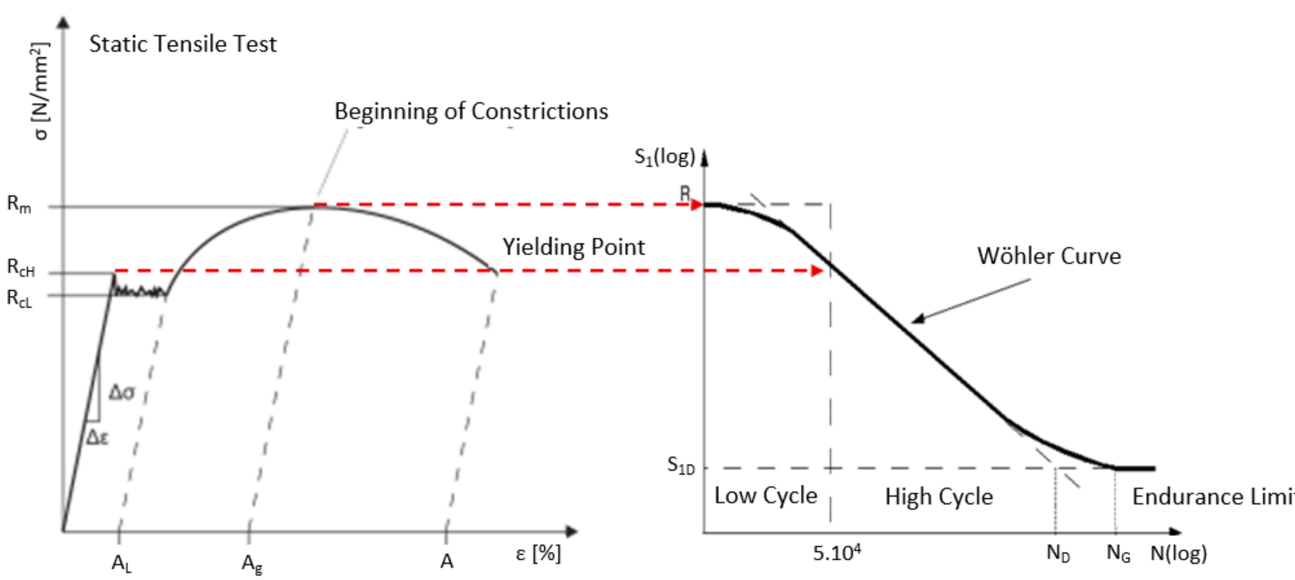


Figure 15. Wöhler S-N Curve

The endurance limit (σ_e) is the point at which the S-N curve flattens out for alloys that are noticeably ferrous. No matter how the loads are cycled, failure does not occur below a particular endurance limit. In design of the axle housing the structure is suitable to withstand the cyclic load of GAWR which is endurance limit for the axle housing. However, in accelerated test conditions, the load that results in reasonable fatigue failure in a short time is investigated, so that it is much higher than the endurance limit. Also, as mentioned in section 2.3, this load is below yielding load. In order to define the accelerated load specifically for the structure, in this study, S-N curves for both crack initiation and crack propagation were generated using fatigue test data. To generate S-N curves, a bunch of tests were performed under a controlled loading environment and the data collected as listed in Table 4. The graphs plotted with the data and fitted to the S-N curves as seen below Figure 16 and Figure 17. Figure 17 shows crack initiation fatigue life drop corresponding to applied stress increase. Data is obtained from 27 housings fatigue bench tests. In each test, the crack initiation cycle and location were recorded as listed in above Table 4.

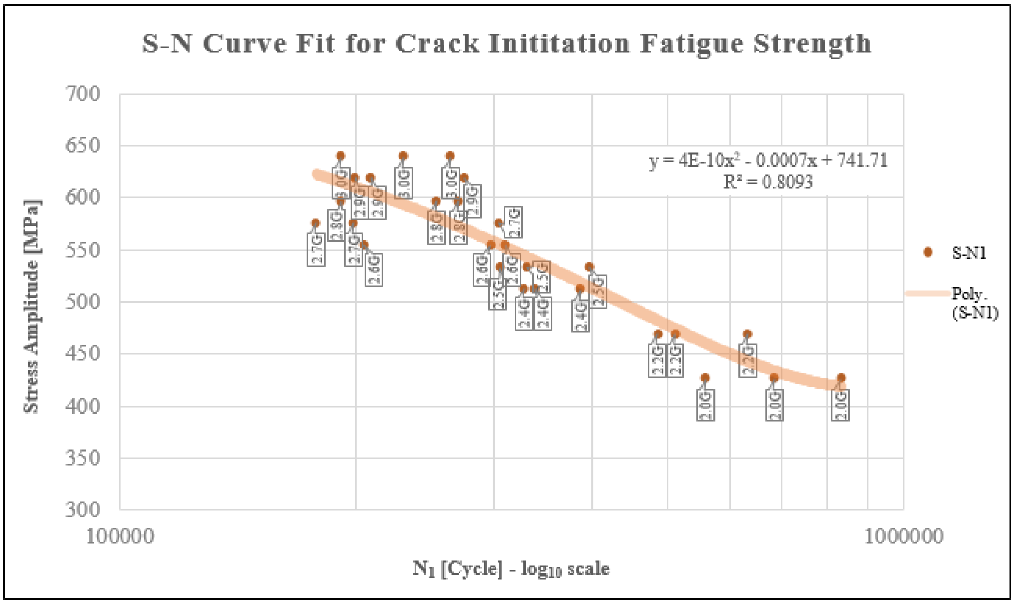


Figure 16. S-N curve fit for crack initiation fatigue strength

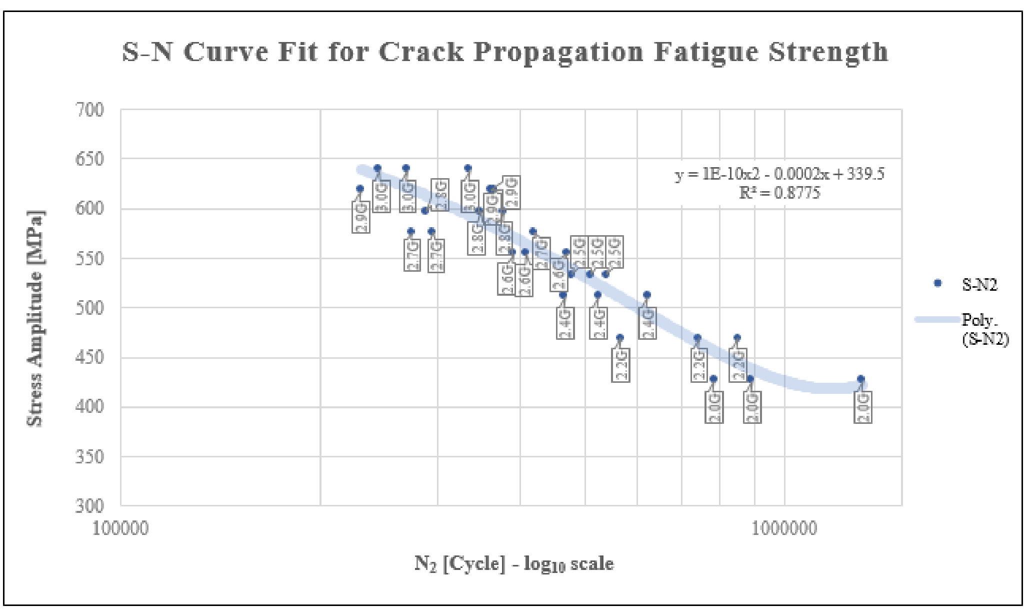


Figure 17. S-N curve fit for crack propagation fatigue strength

Similarly, Figure 18 shows fatigue life drop at a defined (critical value for strength) length crack propagation corresponding to applied stress increase. As expected, the curves both in Figure 16 and Figure 17 match with Wöhler curve (Figure 15) characteristics, especially for the loads between 2.2G and 2.8G. As stated in section 5.1, after some point the load increase results in unrealistic failures. That's why the study will be limited with the load up to 2.8G.

5.3. Time Saved with Accelerated Fatigue Tests

Even if the vehicle road tests can be accelerated by bench fatigue tests, they are still long-lasting and expensive for companies [16]. In order to get an advantage on the market the duration of the bench tests should be decreased. In this study, time elapsed during the tests were recorded and given in Table 4. Fatigue test durations for all tests were performed (Figure 18) and simplified plot as averaged test duration for each load level (Figure 19) shown below:

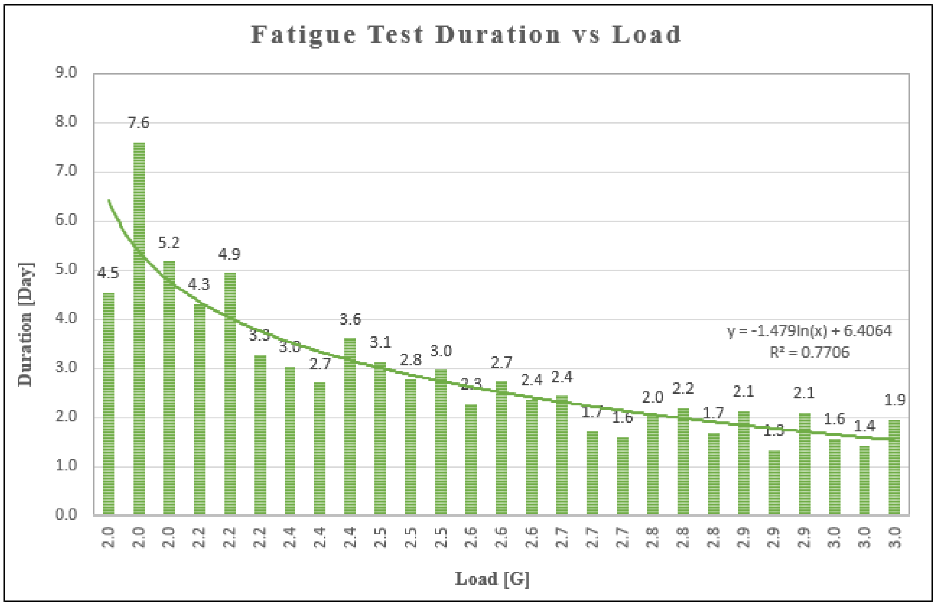


Figure 18. Fatigue test duration vs load

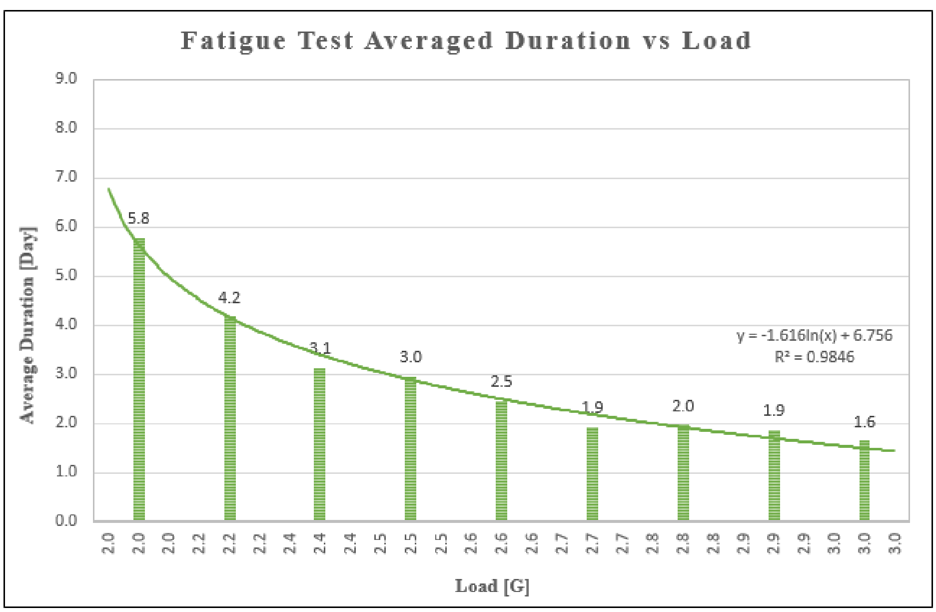


Figure 19. Averaged fatigue test duration vs load

The plots show that the test duration logarithmically drops with the increase of the test loading. Which means, if the optimum loading is set to higher than the default validation value, there is a chance to save time and money with high rate.

6. Conclusion

This study was focused on reducing long-lasting fatigue testing time by increasing the load. For this purpose, the behavior of the axle housing against static and fatigue loading and its reaction for them were measured, and the obtained data were presented in numbers. Preserving the vehicle riding conditions and material properties, accelerated fatigue tests were performed, and the structures failures were observed. Plotting the axle housing's S-N curve was attempted utilizing all of the test findings that were acquired. These graphics specifically belong to heavy commercial axle housing and can be used for the fatigue life prediction [17]. By taking into account not loading excessively

(≤ 2.8G), any increase in the load will turn with a gain of decrease in time and spent money on the testing with a rate given in Figure 19. By the study, a certain decrease of time is achieved. According to a simple calculation with the obtained data, 50% increase in the nominal load saves up to 351.2% in testing time. This is a magnificent gain in terms of rivalry in the automotive industry.

The study demonstrates that by selecting the ideal load for the axle housing fatigue strength, the product's fatigue acceptance criteria may be reformulated to a financially advantageous value and provide a load range for future accelerated fatigue testing.

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Nomenclature

σ, S	: sigma, stress value (MPa)
ε	: epsilon, strain value (no units)
E	: capital epsilon, elastic modulus (MPa)
σ_m	: mean stress (MPa)
σ_a	: alternating stress (MPa)
σ_y	: yield stress (MPa)
N	: fatigue life (cycles)
G	: gravitational force (kgf)

Conflict of Interest Statement

There is no conflict of interest in the study.

CRediT Author Statement

F. Dilay Aksoy: Conceptualization, Methodology, Data curation, Literature survey, Writing-original draft, review & editing
Oğuzhan Çamoğlu: Model Analysis
Olcay Dağcı: Model Testing
Onur Balcı: Supervision

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