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INVESTIGATING THE FAILURE OF LEAF SPRINGS IN AUTOMOBILE SUSPENSION ON GHANA ROAD

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ABSTRACT
This study investigates failure of leaf springs used in the suspension system of heavy-duty vehicles in Ghana. Primary and secondary data were collected using both open and closed ended questionnaires. Welders and fabricators of Sarkyoyo enterprise at the Suame Spare parts dealership area in Kumasi were engaged in the survey. The elastic strain and stress mathematical models were used to determine the stress points in a loaded leaf spring with the aid of ANSYS. The factors considered in the analysis were the leaf spring SAE design specification, the recommended Ghana Highway Authority load limit for heavy-duty vehicles and the terrain. Analysis was done for both the standard and variable curvature leaf springs. The mode of failure was found to be fatigue loading. The causes of failure were determined to be loading beyond the recommended 43 tons per wheel limit, bad roads and reckless driving. It was also observed that loading causes the edges of the leaf spring to bend outwardly from the top, making the edges more prone to failure. Results further showed that the leaf spring with variable curvature recorded strain energy 2.5 times higher than the standards leaf spring.

Keywords: *Suspension System, Leaf springs, Heavy-duty vehicles, Fatigue loading*

1. Introduction

The suspension system of a vehicle delivers easy handling for a comfortable ride. In addition to this, the suspension system also provides better fatigue life for the automotive components (Zamanzadeh et al., 2015; Frey, 1996). The earliest forms of leaf spring suspension system are still being used in all military vehicles, commercial vehicles, and construction vehicles (Kong et al., 2016). The leaf springs are one of the major parts of the automobile suspension system and their contribution to effective functioning of the vehicle is crucial (Shamim and Anwer, 2014). The main components of an automobile suspension system are leaf spring, shock absorbers and linkages (Amrute et al., 2013). These automobile components enable a relative motion between the wheels (Rajesh and Sreekumar, 2016). A simple form of leaf spring suspension system is used in wheeled vehicles, which mainly has a laminated structure that absorbs energy when the load is applied (Prawoto et al., 2008). The laminated structure deforms with high deflections due to the impact developed by shear and compressive loads, and retained in the original structure when the load is released (Guan et al., 2017). When a vehicle is moved over a dips and bumps on the road, the leaf spring absorbs the shock and the vibrations, thus providing a good comfortable drive (D'Silva and Jain, 2014). The leaf spring helps to control a vehicle by keeping the wheels in contact with the road surface (Hou et al., 2007). When the vehicle moves over a dip and bump, these springs help to prevent it from bouncing uncontrollably. The main use for a leaf spring is carrying the whole weight of the vehicle (Kumar et al., 2014). The semi-elliptical leaf springs are normally multi-leaf springs in automobile vehicles (Gowd and Goud, 2012). The main disadvantage of leaf springs is the stress created during running conditions, which restricts the use of more expensive high-strength materials. These components are subjected to millions of varying cyclic stresses leading to failure ultimately (Zadeh et al., 2000, Kong et al., 2014, 2016). The failure of the leaf spring could lead to fatal accidents; thus, it is also considered as a safety component. The leaf spring also have a low flexibility (Kumar and Vijayarangan, 2006).

Leaf springs are a crucial part of a heavy load vehicle and it is necessary to reduce the vertical bumps and vibration impacts due to an uneven road surface by means of consideration in the spring deflection. Investigation shows that frequent failure of the leaf spring suspension system and half of the fractures had deep secondary cracking along the mid-plane, which could lead to accidents. It was observed that the damaged leaf spring has failures due to fluctuating loads, with the static load of the vehicle and road imperfections affecting the payload during its lifetime cycle (Nataraj, M. and Thillikkani S., 2020). Husaini et al., (2019) conducted a failure analysis of the leaf spring of truck colt diesel using finite element method. The the stress intensity factor yielded a value of 22.09 MPa with a load of 26.95 kN. The analysis results show that the value intensity factor is close to the fracture toughness ($K_I \approx K_{IC}$). Therefore, this can cause crack propagation due to dynamic loads (Azom 2012, Samoila A 2011). This fact states that this is one of the causes of leaf spring failure.

In a study done by Charde and Bhope (2012), it was established that the length of the leaf spring plays a significant role in the strengthening of the leaf springs as a collective element. The authors subjected different lengths of the leaf spring to several loads and results indicated that the length of the stacked leaf springs influenced the strength of the spring; shorter graduated length indicated a weaker leaf spring while longer graduated lengths revealing stronger leaf spring. In another study done by Kong (2016), the eye of the leaf spring was analyzed to determine how loading affects the eye. In the study, several diameters of the eye were analyzed and it turned out that the 17 mm diameter spring eye design performed better than all the extreme load cases without failure. Hence a strong leaf spring should have an eye diameter of 17 mm.

A leaf spring was developed for a lightweight vehicle from combined materials to be equal to a steel spring. A total of four materials were assigned to the design namely; Conventional steel, Glass fibre reinforced polymer, Carbon fibre reinforced polymer and Aluminium graphite (metal matrix composite). The analysis of composite leaf springs made up of glass epoxy (62% glass fibre), carbon epoxy (40% carbon fibre), aluminium graphite (5% graphite) and conventional steel were compared. Static analysis was performed to evaluate the weight to strength ratio, total deformation, Von mises stress and strains respectively. A weight reduction of 76.4 %, 81.1% and 65.8% respectively was achieved by using composite leaf springs. Ride comfortness evaluation showed the percentage increase of 127.4%, 167.7% and 146.7%, respectively for Glass fibre, Carbon fibre and Aluminium graphite composite materials. The first natural frequency was approximately 1.2 times greater than the road frequency. The simulated results for fatigue life cycles of leaf spring (10e5 cycles) was observed, whereas, for the conventional steel leaf spring, 2e5 cycles was observed. The results obtained showed that the composite leaf spring can be a good replacement material with overall weight and cost reduction of the component (Naik, et al., 2019).

Design and experimental analysis of composite multi leaf spring using glass fibre reinforced polymer has been carried out. Composite Leaf Spring is found to have lesser stress (67.35%), higher stiffness (64.95%) and higher natural frequency (126.98%) than that of existing Steel Leaf Springs. Conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg, resulting in a weight reduction of 68.15%. Besides reduction of weight, fatigue life of Composite Leaf Springs was predicted to be higher than that of Steel Leaf Springs. Composite Leaf Spring was determined as an effective replacement for the existing Steel Leaf Springs. Simulated models (analytical and FEM) were found relatively stiffer than actual experimental design models of Steel Leaf Springs and Composite Leaf Springs (Mouleeswaran & Vijayarangan, 2007).

The 65Si7/SUP9 leaf springs assembly consists of two full length leaves and ten graduated leaves, four rebound clips of mild steel, four shim pipes with four nuts and bolts, four rivets, centre nut and bolt and a bush of bronze. The master leaf consists of upturned berlin eye at both the ends. The second leaf is provided with a military wrapper to avoid accidents in case of master leaf failure at eye section. All the four specimens were tested under the same stress range and fatigue life was determined. It was observed that, for the alternating stress level of 896–269 MPa, the experimental fatigue life of the leaf spring was 83513 cycles. The fatigue life estimated by SAE spring design manual technique was 69600 cycles, for the alternating stress level of 885–200 MPa. It was also observed that, in the SAE spring design manual approach, the maximum stress (i.e., 885 MPa) is less than the specified maximum stress but the stress range is higher than specified stress range. The same approach with specified stress range gives the fatigue life of leaf spring to be 81600. For the same alternating stress level of 896–269 MPa, the fatigue life was found to be 90763 cycles by graphical method and equivalent stress was 578 MPa. In the analytical method, the fatigue life was recorded as 90304 cycles with 8.13% variation from the experimental results. The SAE fatigue life was also found to be 82348 cycles, with 2.39% variation from the experimental results (Arora, et al., 2019).

Springs are a limited life component. Regardless of how well a spring is maintained or how favourable the operating conditions are, all springs will eventually fail from fatigue caused by the repeated flexing of the spring. Once the spring life limit is reached, a fatigue failure will or has occurred (Clarke et. al., 2005). Factors influencing fatigue life include overloading, shock absorbers, brake adjustments, protective coatings, surface condition and shot peening. The higher the loads or deflections seen by a spring, the lower its fatigue life. A properly functioning shock absorber will tend to reduce the spring deflection as the vehicle hits a bump. Lower spring deflections mean lower operating stresses on the spring which in turn gives longer fatigue life. This is especially true for full taper springs which do not have the high interleaf friction to help dampen spring deflections. Worn or missing shock absorbers must be replaced to maximize spring life (Liza, 2021).

Improperly adjusted brakes can also reduce spring life. Under braking, springs are expected to absorb some of the braking forces. If the brakes on an axle are unevenly adjusted, one spring will have to absorb more than its share of braking force which can reduce its fatigue life (Charde, 2012). Corrosion is one of the major factors in reducing spring life. Proper paints and care during handling and installation can help to slow the spread of spring corrosion. On full taper springs the only acceptable coating is the individual painting of each leaf with zinc-rich paint. This paint may be recognized by its characteristic grey colour. The condition of the spring surface also has an effect on fatigue life. Generally, a fatigue crack will start at some sort of surface defect on the spring leaf. Therefore, care needs to be used when manufacturing and installing springs to reduce these defects to a minimum (Baviskar et. al., 2008). Extensive testing indicates that shot peening can increase the life of springs by a factor of three or more. It is not enough, however, to simply shoot peen the first one or two leaves in an assembly-all leaves must be shot peened. All major vehicle manufacturers specify that their OEM springs have each leaf shot peened (Aher et. al., 2012).

There are several tests that are used to determine the failure of leaf springs, such as, the optical and scanning electron microscopy, hardness and tensile testing, and residual stress evaluation by x-ray diffraction (Mukhopadhyay, 1998). Although all these tests are capable of identifying the cause of leaf spring failure, the commonly used one is the hardening and tensile testing. This test is also the cheapest and can be done using simulation software, such as ANSYS or stress analysis related simulation software. In a study done by (Loganathan et. al., 2020), the relationship between fuel efficiency and the leaf spring material was determined. Loganathan developed a relationship between two composite materials to determine the better option. However, the Carbon Reinforced Polymer composite turned out to be more efficient. A hardness and tensile testing using a simulation software was done and the results turned out that the failure of the metal was due to the fact that the weaker material property was not adequate enough to withstand certain pressures making it unsafe to use. Hence the objective of this study seeks to investigate the failure rate, the causes, and the mode of failure of the leaf spring.

2. Material and Methods

2.1 Research Approach

This study aims to investigate the failure rate of leaf springs in the suspension system of heavy-duty trucks in use in Ghana. The study used both open-ended and closed-ended questionnaires to solicit primary and secondary data for analysis. The questionnaires were administered to welders, black smith and fabricators with some level of interviews at Sarkyoyo Enterprise at the Suame spare parts dealership area in Kumasi in the Ashanti Region of Ghana.

The closed-ended questionnaires were used to solicit specific responses whereas the open-ended questionnaires were used to get information related to respondents experiences and ideas.

The population for this research was the welders and blacksmiths at Sarkyoyo Enterprise in Suame spare parts dealership area. This target group was chosen because upon a previous survey conducted, it was found out that truck drivers do not normally purchase a new leaf spring when a failure occurs. They only take their broken leaf springs to the welders and fabricators for it to be repaired. It was also found that drivers only purchase a new leaf spring when the broken one is beyond repair.

To obtain the sample, a purposive/ judgmental sampling strategy was used. Purposive sampling is a method of selecting a sample based on the researcher's selective judgement rather than random selection. The purposive sampling strategy was used to determine the sample size for this study. With this technique, both welders and blacksmiths were chosen for interview. The total number of artisans employed at this company was 80, out of which, 48 employees were selected for the interview.

2.2 Mathematical Model

A mathematical model was used to determine the stress points experienced in the leaf spring. These models are the elastic strain and stress of a leaf spring. The force per unit area necessarily required to break a material is referred to as the ultimate tensile strength. It is often measured as the stress, which is measured as force per unit area. However, for non-homogenous materials, it is measured as the force per unit width. Stress, as represented in Figure 1, is given as:

$$\sigma = \frac{F}{A_o} \quad \text{(University Physics, 2020)} \tag{1}$$

Where σ represents stress, F represents *F*orce applied and A_o represents the cross-sectional area.

Strain, as represented in Figure 1, which is defined as the measure of the change in length of a body when subjected to a force, is expressed as:

$$\varepsilon = \frac{L - L_o}{L_o} \quad \text{(University Physics, 2020)} \tag{2}$$

Where ε is the strain; Lo and L are the original and final lengths respectively.

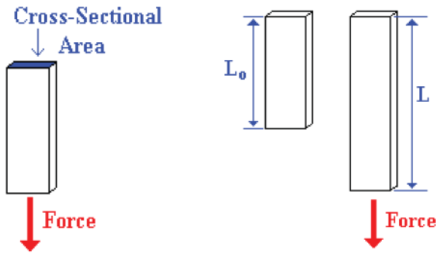

Fig. 1. Changes In Length Observed In The Direction Of Force

However, for laminated semi-elliptic leaf spring, the stress and strain are represented as the bending stress and deflection respectively.

$$\text{Bending stress, } \sigma_b = \frac{3FL}{nbt^2} \tag{3}$$

Where F represents the force or load exerted at the far edges of the leaf spring, L represents the length of the leaf spring, n represents the number of leaf springs, b represents the breadth of the leaves and t is the thickness of the leaf.

Total deflection, $\delta_{max} = \frac{3FL^3}{Enbt^3}$ (4)

Where F represents the force or load exerted on the leaf spring, L represents the length of the leaf spring, E represents the modulus of elasticity, n represents the number of leaf springs, b represents the breadth of the leaves and t represents the thickness of the leaf.

2.3 Simulation

ANSYS (version 18.2) software was used in the finite element analysis (FEA) of the leaf spring failure. Figure 2 is a picture of the leaf spring used in the simulation. The vehicle has two kinds of weight; dry and wet tons.

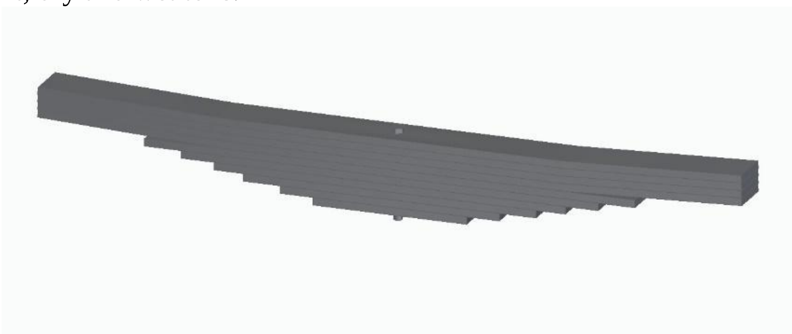

Fig. 2. Leaf Spring

The leaf spring was drawn to dimension using modelling software (i.e. Solid Edge ST10). The dimensions used were Lengths (266.7 mm, 381 mm, 506 mm, 609.6 mm, 723.9 mm, 850.9 mm, 1219.2 mm of four parts), breath (76.2 mm), and thickness (12.7 mm). Structural steel was selected for the leaf springs, with a modulus of elasticity, E, of 200 GPa, Figure 3 illustrates a real-life assembly of the leaf spring.

Fig. 3. Real-life Leaf spring

The assembly drawing of the model was then exported to the ANSYS workbench Project schematic environment (See Figure 4) for the simulation.

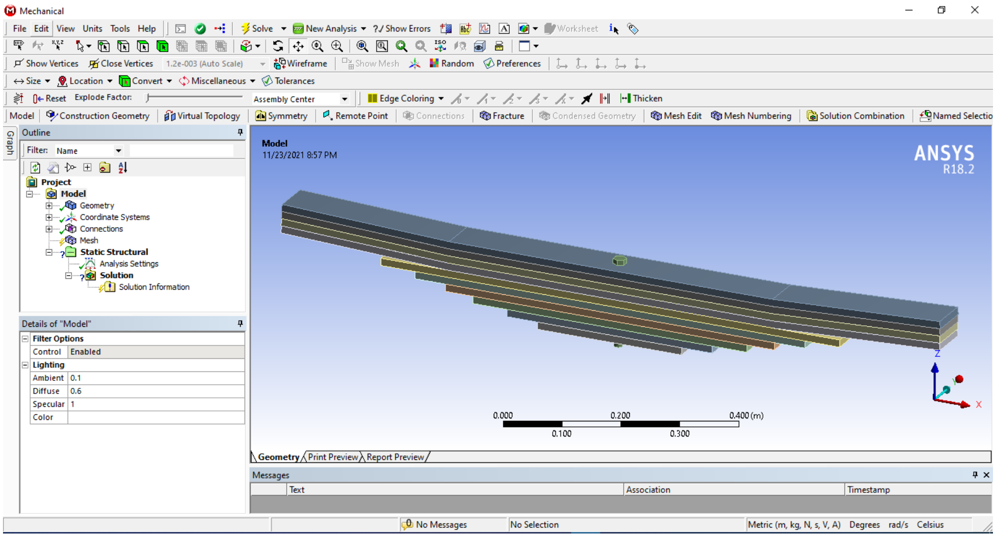

Fig. 4. The model window with an imported model for simulation

Figure 5 illustrates the algorithm used for the simulation. The algorithm summarizes the steps detailed above. It commences from “start” and stops at “end.” There is a question node to determine whether the process needs to be redone to have a more accurate result.

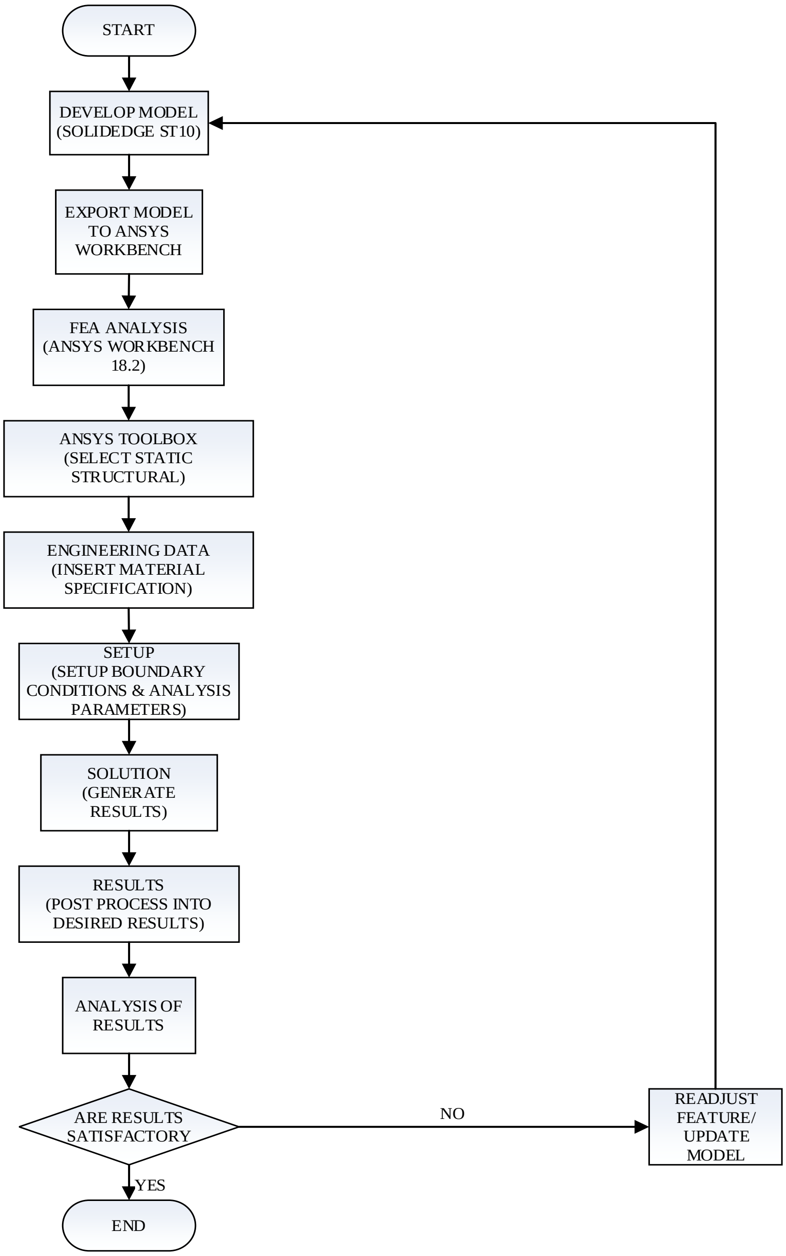

Fig. 5. Algorithm for the Simulation

3. Results and Discussion

3.1 Demography of Respondents

Forty-eight (48) employees at Sarkyoyo Enterprise were interviewed for this study with a 60% response rate, all the respondents were males. Twenty-five percent (25%) of these respondents have been working at the firm for 1-5 years, 42% have been working in the firm for 6-9 years, while 21% have been working at the firm for 10-15 years and 12% for more than 15 years (Figure 6).

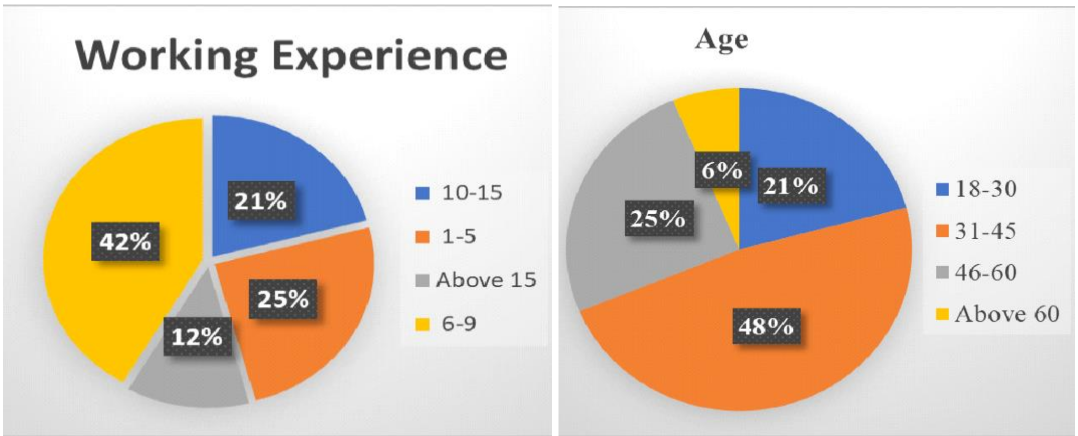

Fig. 6. Working experience and Age

From Figure 6, ten (10) of these respondents were 18-30 years of age which is about 21%. Twenty-three (23) of the respondents were 31-45 years of age representing 48%, twelve (12) of the respondents were 46-60 years of age, representing 25% and only three (3) of the respondents were above 60 years, constituting 6% of total responses.

All the respondents had at least basic education, of which 48% have an educational background up to the JHS level, 35% have Senior High School education, and 17% of the respondent have Technical School education. None of the artisans have any university or polytechnic education (See Figure 7).

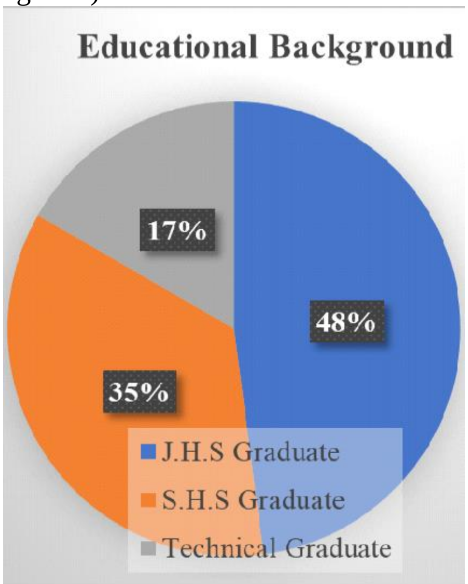

Fig. 7. Educational background

Firms at the Suame Spare parts dealership area produce automobile parts such as steel springs, gears splines, clutch plates that are mostly in high demand by automobile industries in the country. This production, in developed countries, is carried out by Engineers or technicians who have educational background of up to at least polytechnic or technical education. This, however, is not the case at the Suame- spare parts dealership area where only 48% of the respondents have up to technical education (Figure 7). The significance of this is that firms are unlikely to appreciate some engineering principles in the engineering economy, design, and effects of stresses and strains on products or components and parts that when considered can aid in design and production. Also, firms may find it difficult to adopt the ISO 9000 principles in their firms as a result of a low level of education.

3.2 Causes and Mode of Failure of the Leaf Spring

The effects of such failure on the vehicle were discussed. Most respondents gave more detailed explanations of the causes of the failure and very vital information on the effects on the vehicle and its occupants. During the interview, it was explained that regardless of how well the spring is maintained or how favorable the operation conditions are, all springs (new or old) will eventually fail. This may be as a result of many factors.

The first factor mentioned by most respondents was poor road networks found in our country. Most respondents explained that since the spring mostly has direct contact with the axel of the vehicle which is connected to the wheel, it easily experiences the shocks and vibrations that directly come in contact with tires and wheels. It is further explained that though it is the work of the spring to dampen these vibrations and shocks, it eventually fails when the shocks are too much to bear due to the nature of the road. The poorly managed roads in the country accelerate the failure of the leaf spring. The introduction of locally made speed ramps on the road in some parts of the country also causes sudden shocks to the suspensions of vehicles as they are not professionally constructed. This concluded to irregular and uneven road conditions as one of the key factors responsible for the premature the failure of leaf spring.

The second factor that causes the failure of leaf spring is the overloading of the vehicles. According to the respondents, another important key factor responsible to early failure of leaf springs is the overloading of haulage trucks. In Ghana, the allowable weight for a heavy-duty vehicle is 43 tons per wheel (Hammond & Gidisu, 2010). However, according to the respondents, the truck drivers prefer overloading their trucks to about 53 tons per wheel to reduce the time taken to transport their goods. The respondents also mentioned that due to the increase in fuel prices, most truck drivers overload their trucks to make up for the cost of fuel. The spring is designed to give support to the weight of the vehicle and its occupants as well as the weight of the load or goods at a specified quantity.

The third factor that causes leaf spring failure according to responses gathered was the reckless driving of the truck drivers. Some of the respondents raised the argument that some truck drivers have bad driving habits. Most truck drivers, according to some of the respondents, drive recklessly during trips and journeys. Most of the truck drivers over-speed during trips because they want to get to their destination early, get new goods to transport, and make more profit. As a result of over-speeding, the leaf spring fails before the required number of cycles. This concludes the fact that overloading, poor road networks, reckless driving, and the weight subjected to the leaf spring cause it to fail.

The simulation was done for both wet and dry tons of the load exerted by the vehicle on the leaf spring. The values obtained were compared with the analytical calculations to determine the % error as illustrated in Table 1. This also helped to determine the mode of failure and the points at which the failure is experienced the most. As illustrated in Figures 8 to 11, the color graduations indicate the equivalent strain and stress experienced by the leaf spring.

Table 1 - Results Comparison

S/N	Parameters	Analytical result	ANSYS result	% Error
1	Bending Stress, σ_{bdt}	729.746	354.67	51.61
2	Total deformation, δ_{maxdt}	0.00107	3.749	99.97
3	Bending Stress, σ_{bwt}	1094.619	532.01	51.39
4	Total deformation, δ_{maxwt}	0.0016	5.6235	99.97

The Table revealed that the percentage error for the Dry and Wet bending stresses were 51.61% and 51.39% respectively and Dry and Wet total deflection was 99.97%. These high values indicate that the analytical method has a higher percentage error compared with the simulation.

Figure 8, which represents the total deformation for the dry ton exerted on leaf spring, recorded a maximum value of 3.75 mm and a minimum value of 0.50 mm. These values show that the weight of the vehicle causes a slight deflection on the leaf spring. It is also revealing the areas of high strain concentration are closer to the edges of the spring. Hence, failure is more prone to occur in this region.

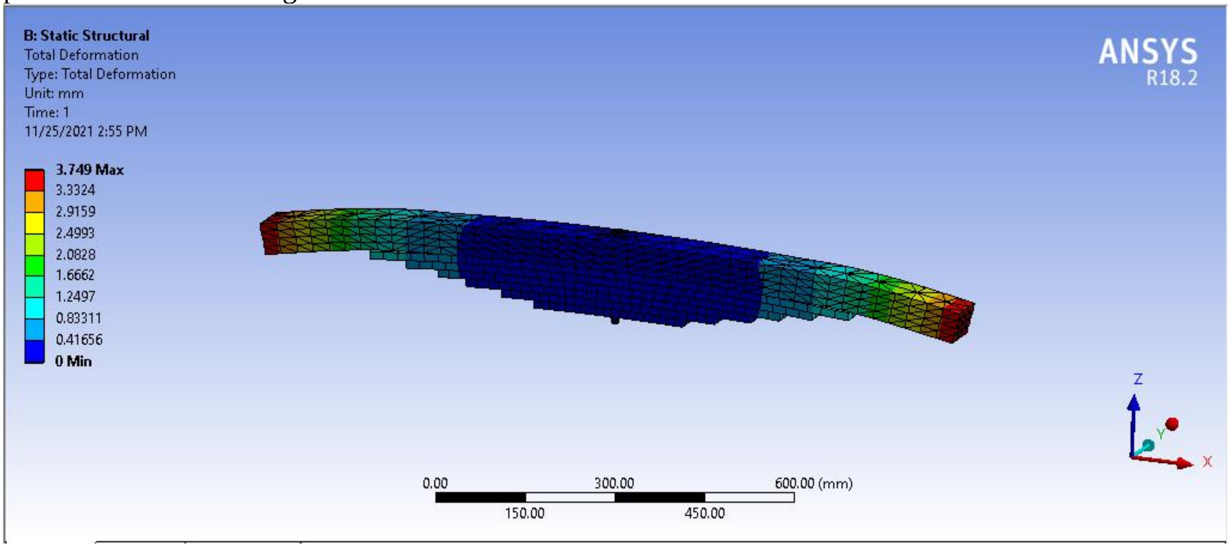

Fig. 8. Simulation For Dry Ton For Total Deformation

Figure 9, which illustrates the total deformation for the wet ton on the leaf spring, recorded a maximum value of 5.62 mm and a minimum value of 0.62 mm. As expected, the resulting values for this wet ton were higher than that of the dry ton. However, the strain was experienced in the same region as the dry tons even though it was higher.

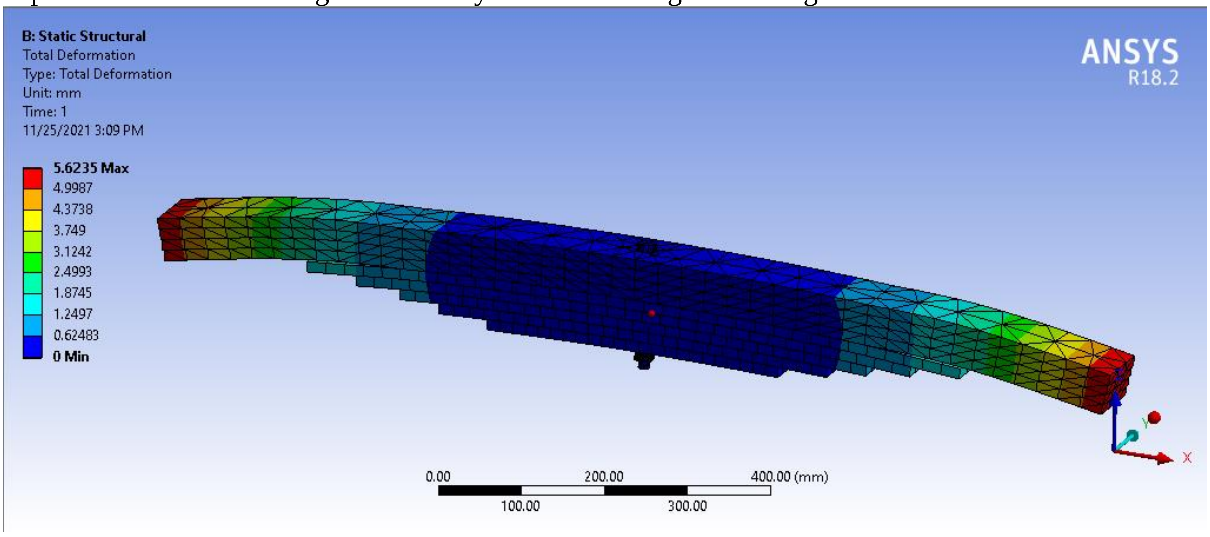

Fig. 9. Simulation for Wet ton for Total deformation

The equivalent stress experienced in the leaf spring for the dry ton recorded a higher value of 354.67 MPa and a lower value of 0.29 MPa (see Figure 10). It could be identified that the stress was experienced around the same region.

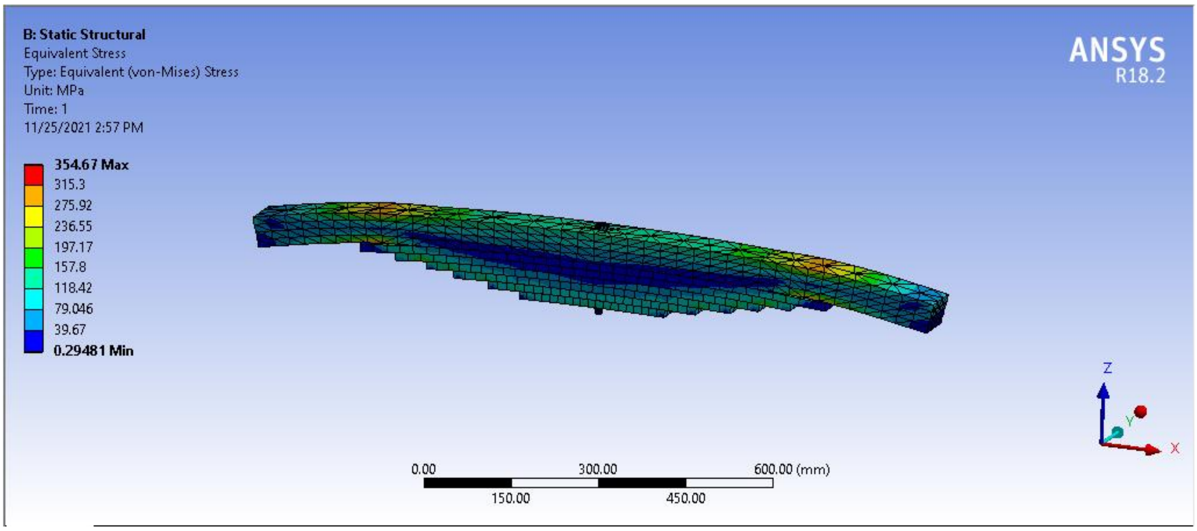

Fig. 10. Simulation for Dry ton for Equivalent stress (Von Mess Stress)

Figure 11, which illustrates the equivalent stress for leaf spring, recorded a high value of 532.01 MPa and a low value of 0.44 MPa. The same was experienced for the region as the dry ton although higher values were recorded for this test.

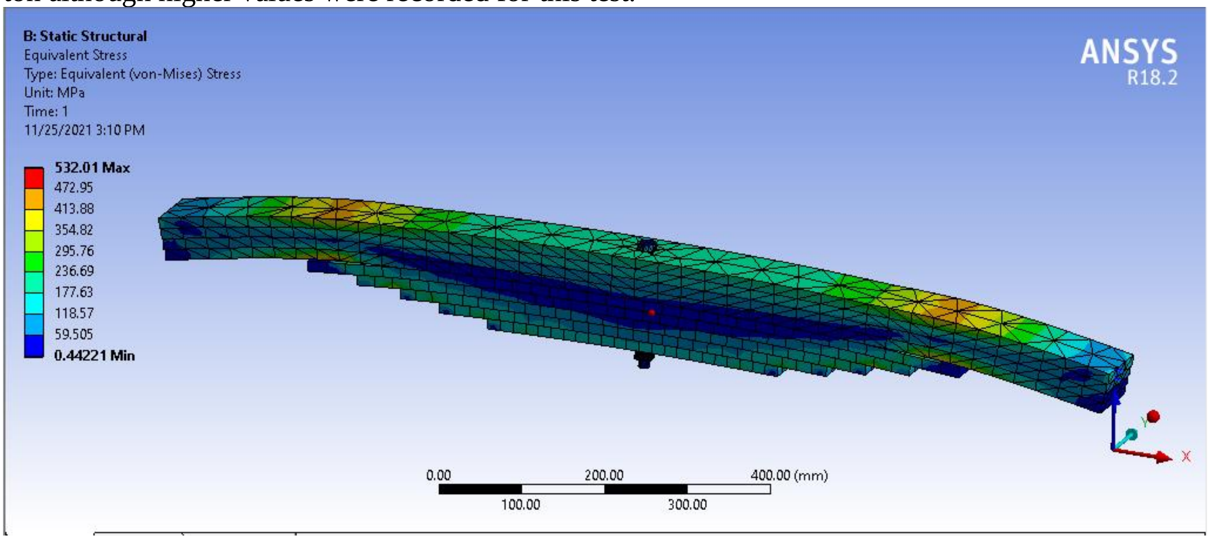

Fig. 11. Simulation for Wet ton for Equivalent stress (Von Mess Stress)

The results revealed that for the dry ton, the weight of the vehicle acts on the spring, which causes it to deflect about 3.75 mm. However, the deflection increased with the wet ton to about 5.62 mm, which indicates that a slight weight added has a direct impact on the spring. Hence loading and unloading of the vehicle directly affects the spring and this is true for real-life applications. However, the effects of loading as well as the effects of the road on the spring can cause the spring to fail over time. As seen in the wet and dry tons results for total deflection, the effect of the loads causes the edges of the leaf spring to bend outwardly from the top. This is usually the region where failure mostly occurs in real life. In order to curtail the problem, a new set of leaves could be introduced to share the load with the current one. This could ultimately relieve the springs of the high amount of pressure experienced. It could allow the region of concentrated stress to move from the edges of the second leaf to the center. This will suggest that the load is evenly distributed in the first leaf spring arrangement. As a result, the leaf spring will perform better and will have a longer life span.

Table 2 shows the results of the deformation and strain energy of the two models of the leaf spring suspensions. By applying the load at the base of the leaf spring and attaching the eyes to the frame of the car while the base is fixed to the axle. By comparing the deformation result of the two models, the standard leaf spring model has a lower deformation of 4.9582 mm compared to the leaf spring with a variable radius of curvature because there are gaps between the leaves, and the leaves are bounded by the bonded contact.

Table 2 - Table of Results of Standard Leaf Spring And Radius of Curvature

Model (C4) > Static Structural (C5) > Solution (C6) > Results

Object Name	*Total Deformation*	*Strain Energy*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Strain Energy
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	0.74084 mm	9.688e-003 mJ
Maximum	4.9582 mm	4015.3 mJ
Average	3.9995 mm	
Minimum Occurs On	master leaf	
Maximum Occurs On	graduated leaf 6	graduated leaf 1
Total		1.3696e+005 mJ
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

Model (B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	*Total Deformation*	*Strain Energy*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	
Definition		
Type	Total Deformation	Strain Energy
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	0.66464 mm	1.3024e-002 mJ
Maximum	5.8493 mm	10098 mJ
Average	3.8804 mm	
Minimum Occurs On	master leaf	
Maximum Occurs On	master leaf	Graduated leaf 6
Total		1.4676e+005 mJ
Information		
Time	1. s	
Load Step	1	
Substep	1	
Iteration Number	1	

The strain energy of 4015.3mJ of the standard leaf spring is lower compared to the leaf spring with a variable radius of curvature which is 10098mJ. From the two leaf springs, the leaf spring with a variable radius of curvature having lower equivalent stress improves the ability to carry heavier loads and ride comfort as compared to the standard leaf.

3.3 The Fatigue Life Cycles and Failure Rate of a Leaf Spring

The number of cycles it takes for a leaf spring to fail is referred to as the failure rate. In other terms, it is the leaf spring's lifespan. The longevity of the leaf spring can be influenced by a variety of factors. These factors include the environment (road conditions), the material used in the manufacture of the leaf spring, exceeding the leaf spring's load-carrying capacity, and irresponsible driving on the part of the driver.

The fatigue life of the two models was analyzed. The fatigue tool uses the stress life type of analysis and the stress component used here is the equivalent stress (Von-mises). The life units are described in cycles. Figures 12 and 13 show results of cycles.

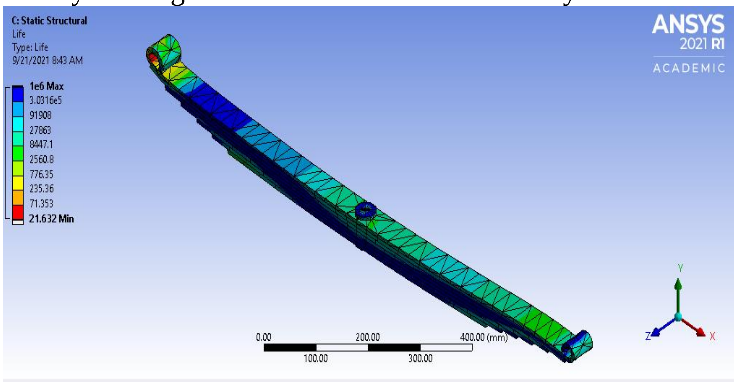

Fig. 12. Fatigue *life of standard leaf spring*

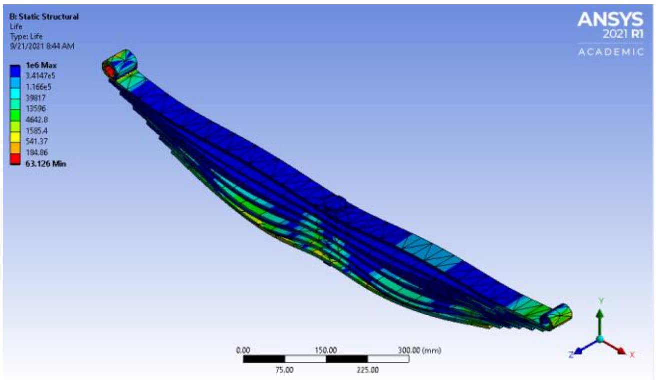

Fig. 13. Fatigue *life of leaf spring with a variable radius of curvature*

4. Conclusion

The aim of this projects as to investigate the failure of the leaf spring. A survey was done to find the causes of the mode of failure in the leaf springs. The survey was at the Sarkyoyo enterprise at the Suame vehicle spare parts dealership area in Kumasi. Sarkyoyo enterprise was chosen because of the diverse departments they have as well as the relevance of their work to this research. From the results obtained from respondents and the analysis done, the following conclusions are drawn:

- The causes of failure were determined to be loading beyond the recommended 43 tons per wheel limit, bad road network and reckless driving
- Failure begins at the edges of the leaf spring since the effect of loading causes the leaf spring system to be bent outward
- The total deformation for the wet ton on leaf spring recorded a maximum value of 5.62 mm and a minimum value of 0.62 mm whereas the equivalent stress experienced in the leaf spring for the dry ton recorded a maximum value of 354.67 MPa and a minimum value of 0.29 MPa

- The results revealed that for the dry ton, the weight of the vehicle acts on the spring, which causes it to deflect about 3.75 mm. However, the deflection increased with the wet ton to about 5.62 mm, which indicates that a slight weight added has a direct impact on the spring. Therefore, loading and unloading of the vehicle directly affects the spring
- Comparing the deformation result of the two models, it can be seen that the standard leaf spring model has a lower deformation of 4.9582 mm compared to the leaf spring with a variable radius of curvature because there are gaps between the leaves, and the leaves are bounded by the bonded contact.
- The leaf spring with variable radius of curvature recorded strain energy 2.5 times higher than the standard leaf spring
- The leaf spring with a variable radius of curvature have lower equivalent stress and, therefore, improves the ability to carry heavier loads and ride comfortably compared with the standard leaf.

4.1 Recommendation

Ride comfort is very essential to the individual in the vehicle as direct impart with the vibration of the road may cause severe health hazards to the occupant(s) of the vehicle. The ability of the heavy-duty vehicle to carry standard loads and the extension of lifespan is very important to consider when designing the suspension system of which the leaf spring is a part. The leaf spring helps to reduce the vibrations from the engine and the road to the occupant(s). In most heavy-duty vehicles in Ghana, the application of the leaf spring is the most popular spring component used in the suspension of the vehicles. It is therefore important to know some factors to cause the failure of the leaf spring and the effects it has on the vehicle and occupant(s).
It is therefore recommended that

1. The driver(s) of heavy-duty vehicles should practice good driving skills and behavior during driving.
2. The owner(s) or driver(s) of the vehicles should engage in good maintenance skills.
3. The driver(s) should avoid overloading of vehicles as it causes reduction of the fatigue life as well as the early failure of the leaf spring.
4. The manufacturers of the leaf spring in Ghana should consider the use of other materials or parameters for the making.
5. The road commission of Ghana should see to it that principal roads in the country that most load-carrying vehicles trip along are well maintained to reduce the bumpiness of the road supporting vibration and fatigue loading.

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