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Investigation of a Vehicle Tie Rod Failure In Relation To the Forces Acting On the Suspension System

Owunna Ikechukwu[1], *Ikpe Aniekan[1], P. O. Ebunilo[2] & Ememobong Ikpe[3]
[1]*Department of Mechanical Engineering, Coventry University, West Midlands, UK.*
[2]*Department of Mechanical Engineering, University Of Benin, Benin City, Nigeria*
[3]*Department of Instrumentation and Control, Exxon Mobil Producing Nigeria, Eket, Nigeria*

ABSTRACT: A vehicle steering is connected to the steering gear to enable the steering wheel rotate the wheels, while a tie rod is part of the steering mechanism that serves as linkage between the steering gear and the wheels. The tie rod functions by ensuring proper alignment of the wheels, such that the inner and outer edges of the tires are protected from wear. A vehicle exposed to rough terrains, potholes, speed bumps or minor accident is subjected to horizontal, vertical and lateral loading conditions acting on the suspension system and distributed to other linkages including the tie rod. Under such condition, a vehicle tie rod can under compressive or tensile force characterised by buckling. Consequently, tie rod ends can also wear out, causing misalignment of the wheels and putting the lives of passengers and drivers in jeopardy. The various causes of tie rod failure and factors affecting the tie rod performance were investigated in this paper. Moreover, to determine the severity of tensile and compressive forces acting on a vehicle suspension system, McPherson suspension model was simulated in ADAMS software and the result showed a maximum tensile load of -13,340.3838N and a maximum compressive load of 18,563.7102N respectively. In some cases, the compressive load which often results in buckling failure of the tie rod may not need to be as high as 18,563.7102N before the tie rod fails, as other several factors (fatigue, corrosion, poor manufacturing route, misalignment, service loading) considered in this paper were found to operate in sequence with compressive and tensile loads transferred to the tie rod from the suspension system until failure occurs. Hence, vehicle tie rod is the life line of the steering wheel and should be given proper consideration during manufacturing and inspected frequently while in operation to avoid sudden failure.

Keywords: Load, Buckling, Failure, Tie Rod, Steering Wheel, Suspension System, vehicle

I. INTRODUCTION

In automotive a tie rod is the most important part of steering linkage, this is a mechanical component used as a link mechanism to connect centre link to steering knuckle transferring forces to turn the wheel in conventional suspension system and rack to the steering knuckle in McPherson suspension system [17]. One of the key parameter to determine the safety and reliability of automobile system is the functionality of the suspension system. Therefore, it is important that the tie rod operate reliably during exploitation and under severe working condition which is one of the factors necessitating proper design and considerations during manufacturing [13,19,20]. Tie rod is a slender rod with threaded parts consisting of outer and inner ends as shown Figure 1. This paper will focus mainly on the forces acting on a vehicle suspension system (which are transferred to the tie rod and other suspension linkages) as well as other factors that combine with these forces to cause failure of the tie rod during when the vehicle is in operation.

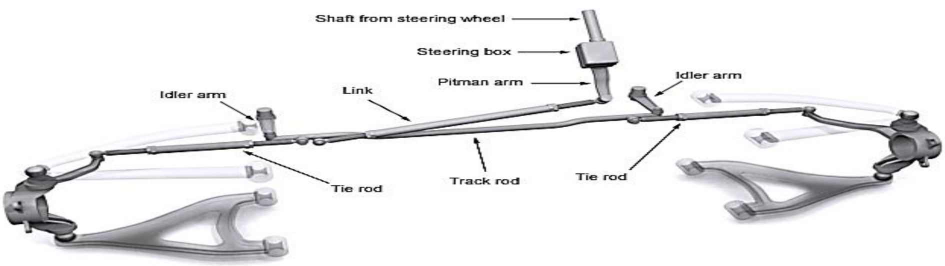


Figure 1: A typical Pitman arm steering system [16]

The importance of steering mechanism or system as part of a vehicle cannot be overemphasised. In fact, without the steering system, changing of directions of cars would hardly be achieved as it is in modern day's applications, or perhaps would not have been possible. Longhurst [16] suggested that the basic components of a typical steering system of a vehicle includes, the steering wheel, steering mechanism (box), the rack rod, the tie rod, and the steering arm as shown in Figure 1. To operate the steering system for a change in direction of a vehicle, the steering wheel is first turn to the desired direction. The movement of the steering wheel is transfer to the steering box through the wheel shaft, and then connects the track rod, which also transfer the motion to the tie rod which is linked to the steering arm to turn the wheels or the tyres. Consequently the tie rod carries the load (force) from the steering system and transfers to the wheels to initiate a rotation and movement [9]. Essentially, as the wheel is also linked to the suspension system, forces are also exerted on the tie rod from that direction, apart from what it experiences from the rest of the steering system. Thus, the design of a tie rod is critical for the effective operations of both the steering and the suspension systems, and of course the entire car. From the above descriptions of a steering system, it can be observed that the tie rod as a component of a steering system, serves as a link between the entire steering system in the suspension of a vehicle. In other words; it serves as a linkage between the two systems [27]. As mentioned earlier, forces are exerted on the tie rod by the movement of the vehicle, and it is expected of the tie rod to be designed to withstand these forces and must not fail catastrophically at certain critical magnitude of the forces. The most fundamental function of a tie rod apart from to aid in the changing of direction of the car is to allow the movement of the proper control of the steering wheel [6]. In addition, it enables adjustment of the steering into different directions and geometries, hence, adjustment of the car's alignments [10,12]. A typical vehicle tie rod is manufactured with a slender structural rod which is much capable of carrying tensile load only, in the sense that, it might fail at a certain compressive load exerted on it, particularly by the suspension system due to bad road conditions like potholes and too many speed bumps [6,7,18]. Due to this reason(s), it acts as a "sacrificial component" or "element" to specifically protect other components considered to be 'vital', such as the rack gear and the steering knuckle from damaging. Besides the protection of these "valuable" components in the event of failure, it is also expected to control the failure effect to ensure that the occupants do not suffer damages. Figure 2 illustrates a typical tie rod at the initial stage of buckling or slight bending and not a complete failure that can result in catastrophes (Trans-Americas Journey 2014).

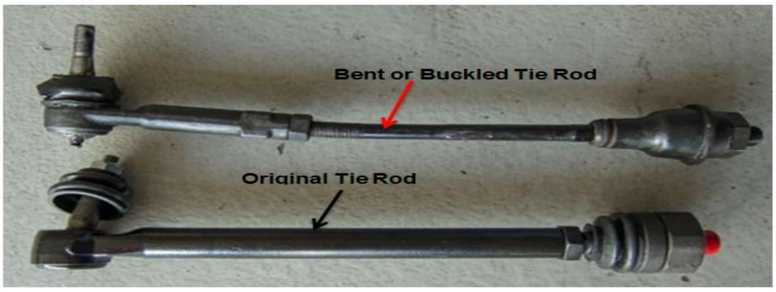


Figure 2: Illustrates a bent tie rod (top) to indicates failure with original one at the bottom [26]

II. CAUSES OF TIE ROD FAILURE

The position and function of the tie rod in a steering system exposes various conditions which leads it to wear and failure. The following factors are the causes of failure in the tie rod.

2.1. Metal Fatigue

The tie rod are subjected to forces when the steering wheel is been turned, the fitting at both ends bear the maximum force exerted by the turning wheel also the threaded section that connect the tie rod ends are subjected to constant vibration and cyclic forces. For example, constant vibration and repeated impacts leads to a phenomenon called fatigue. Final fracture occurs as a result of progressive crack growth where the part can no longer withstand load [25].

2.2. Corrosion Failure

Material corrosion is highly destructive when it occurs on a vehicle tie rod, and when in contact with moisture undergoes surface and pitting corrosion attacks resulting in stress corrosion cracking coupled with the effect of applied forces. This effect has the tendency of speed up cracks on the tie rod. In other words, several structural materials corrode when exposed to moisture in open air but the effects can be more severe when materials are exposed to certain chemical substances which often initiate pit or cracks that can potentially extend across wide surface area [14,28]. However, tie rods are prone to these defects after a long period service operation but manufacturing route and routine checks can help reduce these defects.

2.3. Failure due to poor Manufacture

Inadequate manufacturing of the tie rod or poor manufacturing route can cause failure due to negligence of certain factors. Figure 3 is a typical example of a failed tie rod bolt. Nishida [21] investigated the cause of failure on a tie rod bolt and revealed that fracture initiated by defect during heat treatment had eaten deep into the bolt for some time. Crack growth followed after intense fatigue effect and finally the bolt failed as it crossed over a slit bump

Figure 3: A failed tie rod bolt [5]

2.4. Failure due to Overload

Most accidents occur as a result of impact of vehicle with a non-compliant object. For example, the impact generated when a concrete bridge support is slammed by a truck. The impact leads to a full slant 45degrees inclination of the tie rod resulting in failure caused by extreme tensile loads on the tie rod [26]

2.5. Misalignment

Adjustment of the tie rod ends with the steering gear and the wheels is always carried out to align the front wheels and prevent the outer and inner edges of the tire from wearing out. Also, they are aligned to avoid vibration or wobbling when the vehicle is moving in a rough terrain. Consequently if the wheels are out of alignment (misaligned), usually caused by impact on speed bump or pothole, it may lead to visible wobbling of the wheels which in worse case scenarios might result in wear of the tie rod and other linkages on the front suspension of a vehicle [6]

2.6. Service loading

Axle kinematics and installation conditions are determined by minimum and maximum deflection. Preloads usually subject the tie rod to cyclic loading with high cyclic stresses, the main cause is surface roughness and steering instability which can redirect the steering wheel on high way into incoming traffic path. Figure 4 illustrates the cyclic loading condition of suspension tie rod on a passenger car as it increases.

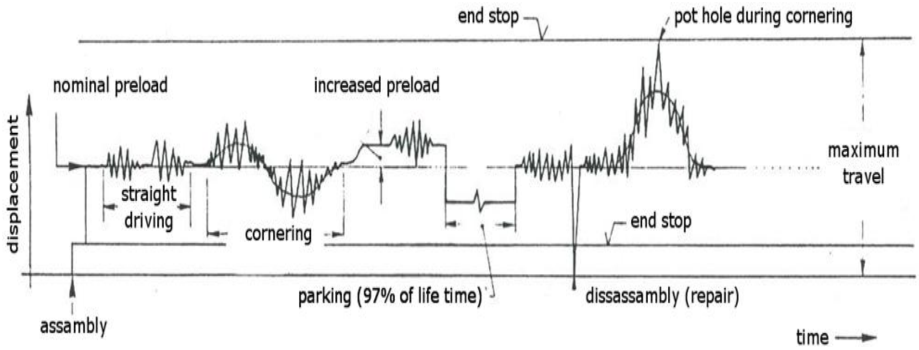


Figure 4: Schematic loading of suspension tie rod of passenger cars

Cyclic loading of tie rod comprises of different types of load cases as shown in Figure 4. The vehicle experiences low amplitudes during its operation on a smooth road, whereas, on a rough road or untilled road surface, cornering and unusual incidents like driving on a road surface characterised by pothole or speed bump will result in increasing loads that requires great consideration during the design and manufacturing stages. Furthermore, the vehicle dynamics while taking a turn on sharp corners at full speed must also be taken into consideration. However a number of scenarios must be considered for safety, good performance and longevity during design and manufacturing route of the tie rod design [14].

2.7. Fatigue

The effect of fatigue on a tie rod is as a result of localized damage process when the component is subjected to cyclic loading. These are accumulative process involving crack initiation or nucleation, followed by propagation and finally fracture of the tie rod. Cyclic loading causes localized plastic deformations at the area of highest stress concentrations in a component. For steel materials, the size of crack at the initiation stage a_o is of the order of a couple of grains of the material. The crack initiation size can be estimated using linear fracture mechanics [15,23].

$$\boldsymbol{a_o = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{\Delta S_e}\right)^2} \qquad 1$$

Where

ΔS_e is the stress range of fatigue

ΔK_{th} is the range of the threshold intensity factor for R= -1

Fatigue damage is mostly linked with cycle ratio n_i/N_{if} where number of applied stress are denoted by n_i and N_f. Moreover, strain cycles and fatigue life are combination of stress or strain amplitude and mean stress levels. The fatigue life N_f can be obtained from baseline fatigue data generated from constant amplitude loading tests. The three commonly used methods in which the fatigue life of a material can be assessed are as follows;

A. Stress Life (S-N) Method

This method is dependent solely upon the stress levels; this method is the least accurate, particularly for low-cycle application. In any case it is the most conventional method, since it is the most straightforward to actualize for a wide range of design applications. It also has adequate supporting information, and most suitable for high-cycle application.

B. Strain-Life (E-N) Method

This involves more detailed analysis of localized areas in plastic deformation, where the material life estimate is made based on stress and strain. This technique is particularly good for low cycle fatigue application.

C. Fracture Mechanism Method

In this technique, assumed cracks are used to predict its growth with respect to intensity, and are mostly used in periodic inspection program of massive structure [11] Sub-surface fatigue initiated cracks could be recognized by the presence of an oval fatigue pattern (fish eye) on the fracture phase which is brought about in low alloy steels by the presence of non-metallic inclusions which is created by fatigue. Low alloy steels break between 10^7 and 10^8 cycles while fatigue facture at a gig cycle level might be dependent upon 10^9 or 10^{10}cycles. High frequency fatigue could be influenced by increase in temperature due to plastic deformity. However, the rate of dislocation will be generally slow in contrast with conic viscosity and the presence of hydrogen embrittlement can prompt fish-eye fracture [8]. Figure 5 shows the stress amplitude for certain number of cycles and their resulting failure effects in high strength steel.

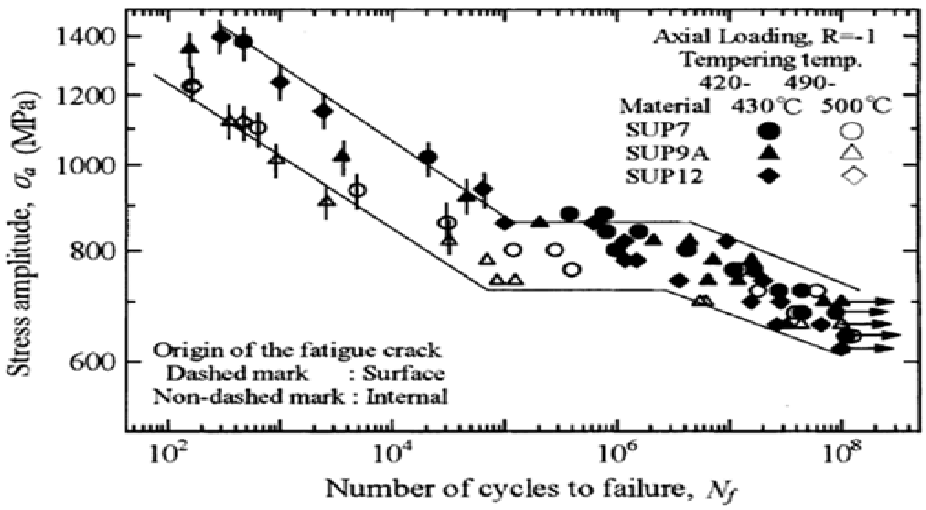


Figure 5: S-N Diagram for high strength steel [8]

Rate of crack propagation in low alloy steel (high strength) is given as

$$\frac{d_c}{d_N} \infty \frac{(\Delta K)^4}{\mu U \sigma^2} \qquad 2$$

Where
μ is given as shear modulus
σ is given strength of alloy
U is the energy required for cracking a unit area by (from) fatigue.
Also fatigue characteristics of load cycle is given as

$$\frac{\Delta \varepsilon}{2} = \frac{\sigma_f}{\varepsilon (2N_f)^b} + \varepsilon_f (2N_f)^c \qquad 3$$

Frequency is the rate per second of vibration constituting wave in a component and the wave can be obtained by dividing the speed of the wave by the wave length. This is one of the threats exhibited by a tie rod in its service condition. It is important for a component's working frequency to operate below its natural frequency in order not to be excited into resonance. In this paper, the working frequency of a tie rod [1] can be expressed given in equation 4

$$f(\text{Hz}) = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \qquad 4$$

Where K is the stiffness constant and is given as

$$K = \frac{AE}{l} \qquad 5$$

Where
f is the frequency in Hertz
m is the mass (load) in Kg
E is the modulus of elasticity
l is the length of the tie rod
A is the cross sectional area of the tie rod

2.8. Buckling

Rasmus [22] reported that buckling takes place when deflection values of a structure under compression or tension increases constantly to a critical state as a result of changes occurring in geometry of the structure due to compressive forces. Buckling can be observed on geometry of a structure when the radius is smaller than the length. Buckling of a tie rod distortion in its equilibrium position can result in catastrophic failure, which makes bulking an imperative parameter for engineers to consider during design [4]. This phenomenon occurs when loading impact results into critical stresses that are lower than the material yield strength, causing yielding before buckling failure occurs [24]. Columns are straight bars characterized with slenderness ratio of L/R ≥ 100. Load impact on the tie rod is mostly compressive, and a stationary car is subjected to more compressive load compared to a moving vehicle. Therefore, the working strength of the tie rod is given as allowable working stress multiplied by minimum cross sectional area [17]. The formula for critical loading is given as Euler equation, which states that the dimension and modulus of elasticity are function of critical load and not a function of the material strength as shown in equation 6 [24]

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} \qquad 6$$

Where P_r is critical load
E is young modulus.
I is second moments of area.
L_e is effective length.
The critical stress follows:

$$\sigma_{cr} = \frac{P_r}{A} = \frac{\pi^2 E}{\left(\frac{L_e}{R}\right)^2} \qquad 7$$

Where
R= radius of gyration given as $\sqrt{I/A}$ 8
When radius of gyration is smaller the lower critical stress is attainable. The effective length is affected by the condition of the column [24].

2.8.1. Deducing Critical Load

From Euler equation shown in equation 6

$$P_{cr} = \frac{\pi^2 \text{EI}}{L_e^2}$$

With two ends pined, the end condition $L_e = L$
Considering the function L_e/R, the Euler equation can be applied to state slenderness ratio to give;

$$\left(\frac{L_e}{R}\right)E \geq \left(\frac{L_e}{R}\right)t \qquad 9$$

$$\left(\frac{L_e}{R}\right)t = \sqrt{\frac{\pi^2 E}{sy}} \qquad 10$$

2.8.2. Control of Tie Rod Failure

Failure of a tie rod can cause instability of the vehicle, thereby, leading to accident. Therefore, it is important to design a tie rod to respond to failure in a controlled manner and not design that may fail abruptly without any indication. The load acting on a vehicle tie rod is mostly compressive forces as shown in Figure 6, which can cause buckling. Buckling of materials are mostly caused by compressive forces, and the resulting deformation of material geometry can be in different forms. Shear forces contributes to buckling failure while bending moments are mostly dominant. When compressive load is applied on a material, depending on the load magnitude, if the buckling is within elastic limit of the material, the material would gain back its original geometry but if the load exceeds elastic limit, the material will deform elastically.

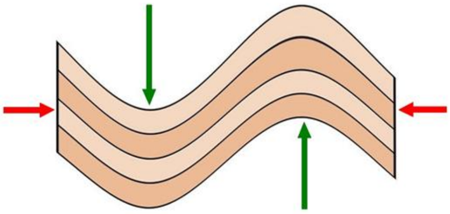


Figure 6: Buckled material caused by compressive force [2]

P_{cr} is given as limit load in elastic region.

$$P_{cr} = \frac{\pi^2 \times E \times I}{l^2} \qquad 11$$

Buckling effect on the tie rod does not imply complete failure, rather, when buckling occurs on a tie rod, it can still manage to transfer motion to the wheel knuckle. Under such condition, the performance of the tie rod may not be as effective as normal condition. In other words, buckling still provides room for the tie rod to be responsive to subsequent loading effects before final failure unlike fracture which can result in abrupt failure without any indication [3]. This must be considered in the design of a tie rod to prevent sudden failure when extremely high forces are generated during the operation of the vehicle. The fracture limit is defined by the materials ultimate strength (σ_u) which is given as;

$$\sigma_u = \frac{F}{A} \qquad 12$$

Where F is the load that results in fracture of the material

A is cross sectional area.

During design, assumption is made in order to design the tie rod such that failure is controlled rather than occurring suddenly. The relationship is given as follows;

P_{cr} is assumed to produce stress (σ_{cr})

$\sigma_{cr} < \sigma_u$

The expression above implies that stresses due to the load that can cause buckling should be lower than the ultimate stress of the material. This will result in controlled failure which will buckle first before final fracture as shown in Figure 7.

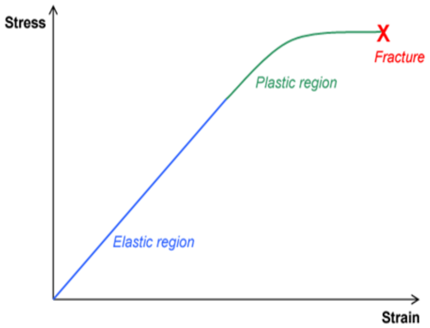


Figure 7: relationship expressing where critical buckling stress to occur [3]

Nevertheless design for ultimate stress involves using non-linear analysis and presenting it on FEA has a lot of challenges. Elastic limit (σ_y) is usually the bases of the tie rod design and more consideration is also given to the tie rod material properties such as the Young's modulus (E) because a given material that exceeds its elastic limit under the influence of applied load is more likely to fail. Also considering the tie rod in complete compression failure will not be brittle, rather it will be ductile. The distinction between them is the time it takes before fracture or material plastic deformation occurs. When maximum load is applied on ductile material, plastic deformation occurs till the material yield point is reached, followed by necking which is an indication of failure prior to total fracture occurring as shown in Figure 8. Plastic deformation is not evidence in brittle materials because crack propagation occurs rapidly and initiated cracks do not reduce, but keeps increasing in size. Whereas in ductile materials crack initiation are slower and consequently reduced as load is removed. It is most preferable to experience ductile failure which presents signs such as unusual noise and stiffness of the steering wheel.

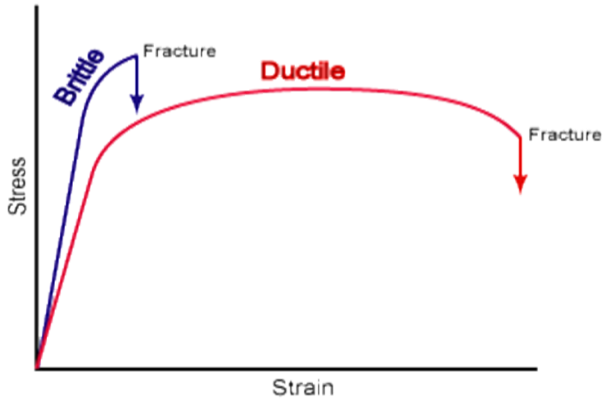


Figure 8: Stress & Strain curve [2]

III. FACTORS AFFECTING THE TIE ROD PERFORMANCE

3.1. Material

The tie rod operates with pushing or pulling principles while transferring motion from one end to the wheel knuckle for stability of the steering wheel and safety during driving. Material strength, price and density are the major factors that should be taken into consideration during material selection for a tie rod, because too high a price will make some manufacturers prefer cheap materials as long as it can carry out the required task, while the material yield strength contributes immensely to the longevity of the tie rod and very high or too low a density may not be appropriate for the tie rod application. Compressive (Buckling) and tensile loads are the significant loads that negatively impact tie rods of which a very high compressive load can cause bending of the material towards its fracture point, due to changing from elastic zone to plastic zone [3]. To avoid the effects of fracture in tie rods, material used for manufacturing tie rods, should have high yield strength which is a considerable factor to keep the tie rod in its elastic zone. Furthermore, the other important factor is material weight, which is directly proportional to the fuel consumption of the vehicle. Therefore the most proper materials for the tie rod application are those with higher material strength, low cost and low density as each one of these material properties has its own way of affecting the tie rod performance.

3.2. Factor of Safety

Engineering components are usually designed with certain allowance in order to enable them carry additional loads more than the intended design load. Factor of safety represents how much of this additional load a component can bear before its final failure. Since the component is to serve as a fuse which can fail when the maximum design load is exceeded, it is always important to consider the factor of safety while designing a tie rod, as it can act as a fail-safe parameter for the tie rod in times of failure.

3.3. Manufacturing route

Manufacturing is the process of making a product and depending on the component to be manufactured, it is important for manufacturers to ensure that all manufacturing criteria are met before the component is sold in the market. While manufacturing the tie rod ends for the steering systems of automobiles, two processes are used which includes casting and forging as shown in Figure 9 and 10 [14]. The interesting aspect of these processes is that it involves easy processing and low cost. As the first step, casting process is used to create the initial geometry of the tie rod using appropriate material selected for the process, followed by forging. By using these processes, the moulding cost can be reduced due to a few steps in the process and also the amount of scraps can be reduced as it could be used for further tie rod manufacturing. The casting conditions are based on changing the moulding temperature, pouring temperature and pouring time of the material which in turn improves the mechanical properties of the tie rod, as shown in the Table1. During the casting process, there are several factors that affect the quality of the tie rod such as, quality of the moulding melts, the type of flow; turbulence and laminar flow at the surface, core blows in the mould cavity, shrinkage, segregation and location dimensions and machining.

Table 1: Casting condition

Mould temperature (°C)	230
Molten temperature (°C)	1550
Pouring time (Sec)	10
Pouring temperature (°C)	950
Water flow rate (l/min)	30
Water temperature (°C)	5

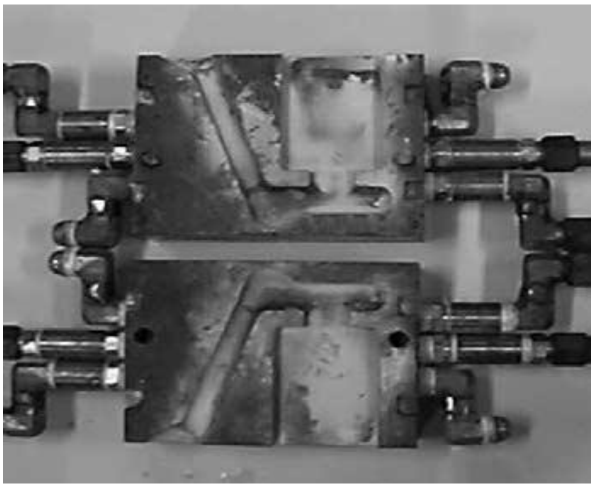
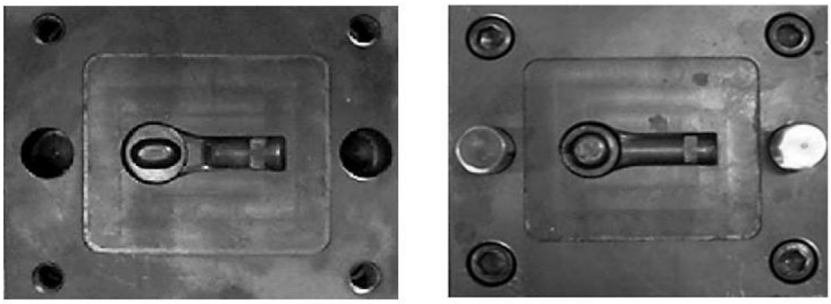


Figure 9: Mould for casting [14]



(a) (b)

Figure 10: (a) The upper die part for tie rod forging and **(b)** lower die part for tie rod forging [14]

IV. LOAD CASE SCENARIOS ON THE TIE RODS USING ADAMS SOFTWARE

Durability of tie rods are measured by its ability to carry loads (forces) generated during driving such as acceleration, braking, cornering, etc. without sudden failure. During driving, there are several scenarios that will exert certain forces on the suspension system which are distributed across the entire suspension including other components which the tie rod, coil spring, idler arm, steering box etc are one of such. In other words, these forces acts on the wheel and are transferred to the tie rod through the suspension system .The load cases can be divided into two categories namely; service loads which have minimal effects on the tie rod and extreme loads which have highly intense effect on the tie rod and their magnitudes on the tie rod are generally different. These loads are assumed to occur during the duty cycle of the tie rod. Table 2 shows the different load case scenarios that are transferred to tie rods from the suspension system. McPherson suspension mode was simulated using ADAMS software and the resulting load effects on the both ends of the tie rod (inner and outer) were calculated to determine the maximum load that tie rod can carry before failure. The maximum results of these load cases given in Table 2, were used to determine the loading effects on the tie rod during operation.

Table 2: Different load case scenarios effects on the tie rods

Load case scenarios	Fx (N)	Fy (N)	Fz (N)	Mx (Nmm)	My (Nmm)	Mz (Nmm)
1G Static	0	0	2,912	0	0	0
7G Bump	15,529	0	23,293	0	0	0
1.10G Brake	4,454	0	4,049	0	-1,336,205	0
Brake and Bump	16,287	0	24,430	0	-1,336,205	
1.30G Cornering	0	-6,564	5,049	-1,969,138	0	0
Cornering and Bump	16,954	-6,564	25,430	-1,969,138	0	0
3G Berm	0	-22,711	7,750	-3,406581	0	0
1.20G Acceleration	-2,005	0	1,671	0	0	0
Acceleration and Bump	12,696	0	22,052	0	0	0
1.00G Reverse Brake	-1,878	0	1,878	0	563,256	0
Reverse Brake and Bump	-16717	0	22,259	0	563,256	0
4G Ditch Hook	0	27,036	774	8,110,908	0	0

ADAMS software was used to measure the impact of all load scenarios on the tie rod as shown in Table 3 and Figure 11. The reason why ADAMS software was employed in this case was to measure the load distribution through the suspension system. Each load case scenarios was simulated using ADAMS software and limited to time interval of 22 minutes and 500 unit steps through a static analysis in order to avoid transient response and spring oscillation. Each load case was acting on both ends of the tie rods (inner and outer) on the Vertical axis (Z-axis).

Table 3: The result of ADAMS software during the load case scenarios

Load case scenarios	**Fz (N) (Vertical load) (Max) N**	**Type of load**
1G Static	231.1326	Compressive
7G Bump	**-13,340.3838**	Tension
1.10G Brake	- 6,873.9779	Tension
Brake and Bump	- 16,970.6959	Tension
1.30G Cornering	1,040.8367	Compressive
Cornering and Bump	-13,654.3468	Tension
3G Berm	1,740.064	Compressive
1.20G Acceleration	2,159.7437	Compressive
Acceleration and Bump	-10,739.2577	Compressive
1.00G Reverse Brake	3,197.1951	Compressive
Reverse Brake and Bump	**18,563.7102**	Compressive
4G Ditch Hook	- 2,641.5033	Tension

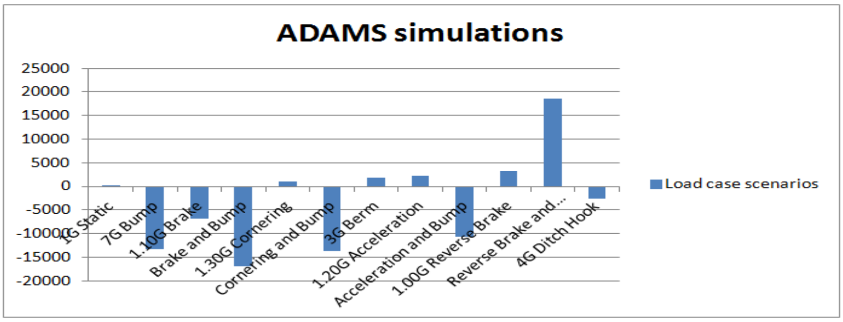


Figure 11: The ADAMS results based on the load case scenarios

From the ADAMS results as tabulated in Table 3 and graphically presented in Figure 11, the positive values denotes compressive load while the negative values represents tensile load. From the Figure 11, it can be observed that the 1G static scenario resulted in a minimum compressive load of 231.1326N, while 4G Ditch Hook scenario resulted in a minimum tensile load of about 2,641.5033N. Furthermore, 7G bump resulted in a maximum tensile load of about -13,652.4787N while reverse brake and bump resulted in a maximum compressive load of about 18,563.7192N and the highest load impact of all the load case scenarios. The highest compressive and tensile load in this case is the critical load factors that a newly manufactured vehicle tie rod can carry before failure. However for a tie rod component undergoing its duty cycle when the vehicle is in operation, failure might take place even before the critical load value is reached, as several other factors during the in service condition of the tie rod as discussed earlier in this paper, impacts negatively on the tie rod. The negative impacts of some of these factors such as Fatigue, Corrosion, poor manufacturing route, misalignment, service loading etc. can hamper the performance of the tie rod and can as well limit its longevity by making it less resistant to external forces which may even be lesser than the critical load values (**18,563.7102N and -13,652.4787N**) depending on the extent of damage the tie rod has been already exposed to.

V. CONCLUSION

The static weight of the car is very low compare to the loads acting on the tie rod in its service condition. For example, the tie rod of a vehicle in stationary position for a longer period of time will still be very active compared to tie rod that has been exposed to rough terrains, potholes, speed bumps and other unusual road conditions. In this paper, Reverse Brake and Bump scenario for compressive load and Cornering and Bump scenario for tensile load were found to have the most severe impacts on the tie rod during its service life, coupled with other factors such as Fatigue, Corrosion, poor manufacturing route, misalignment, service loading, though not too severe as the compressive and tensile forces. Furthermore, lateral forces and longitudinal forces were obtained during the ADAMS simulation. These forces can result in bending of the tie rod, but their effects on the tie rod were neglected due to the small values obtained when compared to compressive and tensile loads in the z-direction. Hence, tie rod manufacturers must pay attention to these forces as well as the material properties during design, as this is one of the ways to make the tie rod less prone to buckling or fracture and failure.

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