Finite element analysis of a car rocker arm

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Abstract

High Density Polyethylene (HDPE) composite rocker arm has been considered for analysis owing to its light weight, higher strength and good frictional characteristics. A 3-D finite element analysis was carried out to find out the maximum stresses developed in the rocker arms made of steel and composite. From the results it was noted that almost same stresses are developed for both the materials (steel and the composite). With this it may be concluded that the stresses developed in the composite is well within the limits without failure. Therefore the proposed composite may be considered as an alternate material for steel to be used as rocker arm.

Keywords
High Density Polyethylene (HDPE), Rocker arm, finite element, modelling, simulation, steel, composite

1.0: Introduction
A rocker arm is an oscillating lever that conveys radial movement from the cam lobe into linear movement at the poppet valve to open it. One end is raised and lowered by a rotating lobe of the camshaft (either directly or via a tappet (lifter) and pushrod) while the other end acts on the valve stem. When the camshaft lobe raises the outside of the arm, the inside presses down on the valve stem, opening the valve. When the outside of the arm is permitted to return due to the camshafts rotation, the inside rises, allowing the valve spring to close the valve. The rocker arm is an important component in the operation of internal combustion engine because of its responsibility in transferring the profile of the camshaft into motion for opening and closing the intake and exhaust valves (Palomaki & Hoffman, 2003).
This mini project focuses on two different types of rocker arms; the existing rocker arm "from the factory" chrome alloy steel rocker arm, and a Glass fibre reinforced High Density Polyethylene (HDPE) composite rocker arm of fuel injection pump.

Both the rocker arms were modelled and analysed in Solid Works. The locations of stress concentrations were also studied in hopes of eliminating them and any possible flaws that could cause failure. As well as optimizing the design (Palomaki & Hoffman, 2003). In this project, an attempt has been made to find various stresses under extreme load conditions for the two rocker arms (Mishra, 2014).

1.1 Background
The rocker arm is an important part of the valve train in fuel injection systems. It actuates the valves through a fulcrum using the lifter and the push rod. It also provide a means of multiplying the lift ratio. Recently there have been an advancement in the research of materials used in construction of rocker arms. Researchers are looking for materials that reduce noise, weight and have higher strength for efficient operation. The most popular materials used for

construction of rocker arms are Steel, Aluminium, forged steel to Stainless steel, alloys and composites (Mishra, 2014). Finite element methods can be carried out to determine the stresses and make a comparison between steel and composite materials to predict the failure modes.

As the turning point of the valve train, the rocker arm is basically a sophisticated lever that channels radial movement from the cam lobe into linear movement at the valve. This is a highly critical process. Due to stresses and vibrations, which are more prevalent during high-speed operation, rocker arms undergo deflection. Severe rocker arm deflection causes inefficient engine performance, and often results in metal fatigue leading to increased wear and friction in the valve train and eventually engine failure.

1.2 Problem statement
Due to problems associated with steel rocker arms like cost and weight, there is need to consider other alternative materials for steel. Analysis of the material properties is important before they can be implemented.

1.3 Main objective
To perform a finite element analysis comparison of a rocker arm made of chrome alloy steel and that of HDPE composite rocker arm.

1.4 Justification
The rocker arm is a very important component of engine. Failure of part makes engine useless and also the procurement and replacement of the rocker arm is costly. Researches done so far clearly indicates that the problem has not yet been overcome completely and designers are still facing lot of challenges especially, stress concentration and effect of loading and other factors. The finite element method is the most popular approach used for analysing fracture mechanics problems. The finite element method is the most popular approach used for analysing fracture mechanics problems.

2.0: Literature review
The most popular materials used in the manufacture of rocker arms are chrome alloy steel, pure steel and aluminium (Husain & Prof Siraj, 2013). Other materials used include anodised aluminium high strength alloy aluminium, chrome moly steel and high strength alloy steel. (Yu & Xu, 2006) (Chung & Kim, 2010). Some rocker arms are made out of glass fibre reinforced high density polyethylene composite (HDPE). There are also other composites like the metal matrix and polymer matrix composites though they are not popular (Mishra, 2014).

2.1 Types of rocker arms
There are various types of rocker arms, and the design specifications are not the same for different types of vehicles (bikes, cars trucks, etc). Even for same type of vehicle category rocker arms differs in some way. Types of rocker arm depend also on which type of Internal-combustion engine is used in a vehicle (i.e. Push Rod Engines, Over Head Cam Engines etc (Husain & Prof Siraj, 2013)

A. *Stamped Steel Rocker Arm*- The Stamped Steel Rocker Arm is the most common style of production of rocker arms. The manufacture of stamped steel rocker is the easiest and the cheapest because they are stamped from one piece of metal. They use a turn-on pivot that holds the rocker in position with a nut that has a rounded bottom. This is a very simple way of holding the rocker in place while allowing it to pivot up and down (Husain & Prof Siraj, 2013).

B. *Roller Tipped Rocker Arm*- This type of a rocker arm is just as it sounds. It's similar to the Stamped Steel Rocker and they differ slightly in a way that you just add a roller on the tip of the valve end of the rocker arm. This addition of a roller is to lessen the friction, for somewhat more power, and reduced wear on the valve tip. The Roller Tipped Rocker Arm still uses the turn-on pivot nut and stud for simplicity. They can also be cast or machined steel or aluminium (Husain & Prof Siraj, 2013).

C. *Full Roller Rocker Arm*- This type of a Roller Rocker Arm is not a stamped steel rocker. They are machined and the materials used are either steel or aluminium. They replace the turn-on pivot with bearings. This type of rocker arm still use the stud from the turn-on pivot but they don't use the nut. They have a very short shaft with bearings on each end (inside the rocker) and the shaft is bolted securely in place and the bearings allow the rocker to pivot (Husain & Prof Siraj, 2013).

D. *Shaft Rocker Arms*- This type of rocker arm is build off from the full roller rocker arm. They have a shaft that goes through the rocker arms and sometimes the shaft only goes through 2 rocker arms and sometimes

the shaft will go through all of the rocker arms depending on how the head was manufactured. The importance of the shaft is for rigidity. Putting a shaft through the rocker arms is much more rigid than just using a stud from the head. The more rigid the valve train, the less the valve train deflection and the less chance for uncontrolled valve train motion at higher RPM (Husain & Prof Siraj, 2013).

E. *Centre Pivot Rocker Arms- In* appearance, a centre pivot rocker arm looks like a traditional rocker arm but there is a much bigger difference. Instead of the pushrod pushing up on the lifter, the Cam Shaft is moved into the head and the Cam Shaft pushes directly up on the lifter to force the valve down. In this case the pivot point is in the centre of the rocker arm and the Cam Shaft is on one end of the rocker arm instead of the pushrod (Husain & Prof Siraj, 2013).

F. End Pivot (Finger Follower) Rocker Arms - The End Pivot or Finger Follower puts the pivot point at the end of the Rocker Arm. In order for the Cam Shaft to push down on the Rocker Arm it must be located in the middle of the rocker arm. (Husain & Prof Siraj, 2013)

2.2 Applications of Rocker arms
A rocker arm is an important component and it is used in the operation of an internal combustion engine because it is responsible for translating the profile of the camshaft into motion for opening and closing the intake and exhaust valves. (Palomaki & Hoffman, 2003).

2.3 Causes of failure in rocker arms
Failure analysis is a broad discipline that includes sectors of engineering such as metallurgy and mechanical engineering. There are a number of failures that might occur, some appear more often than others, which include various types of corrosion or wear by itself, corrosion in combination with wear, and compression to name a few. Failure of engineered products and structures can occur by cyclic application of stresses (or strains), the magnitude of which would be insufficient to cause failure when applied singularly. Structural and mechanical components subjected to fluctuating service stress (or more appropriately, strain) are susceptible to failure by fatigue (Lee *et al.*, 2008). Fatigue is considered as one of the most common causes of structural and machinery component failures which are frequently found in engineering services (Gagg & Lewis, 2009).

Fatigue failure is localised structural damage that occurs when a material is subjected to variable cyclic stresses. These stresses are much lower than the ultimate tensile stress limit when under the application of a single static stress (Suresh, 2001).

3.0: Methodology
This outlines the techniques that were employed in carrying out the finite element analysis of the two rocker arms of different materials. It shows all steps taken done to fulfil the main objective of this project which is to check whether HDPE composite material can be used as a substitute for steel in the construction of rocker arms.

3.1 Solid works modelling
The first step was to examine the part and take the necessary measurements to construct the part. The body of the rocker was an extruded entity and had the front, side, and top profiles cut away. Then holes were cut out to allow for the roller pin and the needle bearing housing to fit inside the body of the rocker.
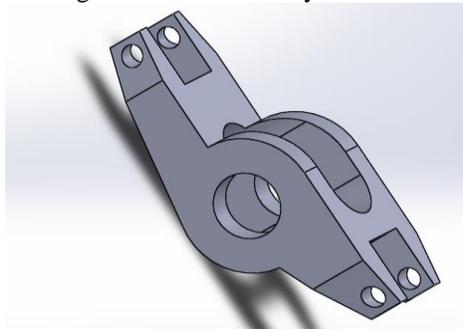

Figure 1: Rocker arm drawn by auto cad software

3.2 Finite element model
3.2.1 Actual part loading
The pushrod internal combustion engine works by transferring a load through the rocker arm to open and close the valve. To determine the load that would be seen by the rocker arm we found the spring rate that would be forcing against the rocker arm. With the spring constant k, a cam profile that gave us the maximum lift of the valve and the seat pressure of the valve, we were able to determine the maximum load on the rocker arm. The cam profile plots were measured by a point of lift at every degree of rotation and can be seen in figures below. In both cases this load was rounded up to be 1.4kN on the tip of the rocker and 2.2kN on the heal of the rocker. This was a static determination of the loads in the rocker arms.

3.3 Experiment
An experiment was done to determine the loads that act on a rocker arm inside an engine. This assumes the inertia loads which are not a maximum at the maximum lift point in the valve cycle would be negligible in comparison to the spring load. Calculations below shows the calculations for the force on the rocker arm due to the spring force. This was done by compressing the spring with a large screw and using a force scale to measure the force exerted. These points were then recorded in Tables 1 and 2. The values obtained in the tables were used to calculate the spring constant and obtaining the forces acting on the heal and tip of the rocker arm.

Table 1: Stock spring rate determination

Lift (m)	Force (N)
0.045	444.8
0.047	578.3
0.050	720.6
0.052	969.7
0.055	1156.5
0.057	1378.9

Table 2: Of high performance spring rate determination

Lift (m)	Force (N)
0.045	622.8
0.047	756.2
0.050	911.9
0.052	1067.6
0.055	1236.6
0.057	1423.4

3.4: Calculations
Calculations to find the spring constant k

$$k = \frac{\Delta y}{\Delta x}$$

For a largest possible triangle to determine the gradient which is k

$$k = \frac{1378.9 - 444.8}{0.057 - 0.045}$$

From the calculation, the value of k is 77.8x10^3
3.4.1: Spring load calculation Data given
444.8N of seat pressure on valve
77.8x10^3 as spring rate
1.5 as rocker ratio
valve lift = 0.00889*1.5
= 0.0133m
$\mathbf{F_{tip}}$ = 444.8 + 0.0133*77.8*10^3
= 1482.3N
Fheal = Ftip*rocker ratio

= 1482.3*1.5

= 2223.4N

3.5: Loading in Model
3.5.1: Constrains
The rocker is constrained by a bolt through the pivot shaft which supports the rocker body by two roller bearings. Since these bearings and shaft are not part of our study they were not included in the FEA. Fixed sliders were introduced on both sides to avoid lateral movements on the part due to loading. The pivoting hole was also constrained by a fixed hinge. These constraints should lead to an accurate model.
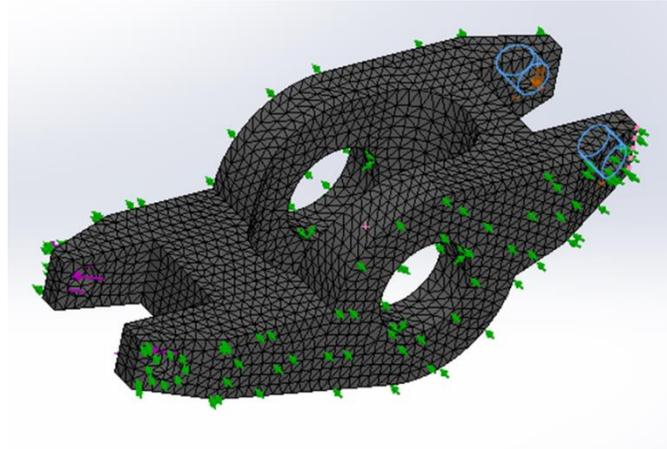
Figure 2: The rocker arm in simulation

The forces were applied at the tips and the heal of the rocker. This was applied to the model as the bearing load with the force at the tip as 1.4kN and that on the heal being 2.2kN. These loads are accurate since they were taken from the experiment and they will yield an accurate model.

3.6 FEA results
After the finite element analysis was completed, the data was collected, and the two rockers were compared. In both designs there are stress concentration areas. The results will be shown in the preceding chapters.

4.0: Finite element results and analysis
4.1 Results
From the results of the finite element analysis done was observed that that maximum stresses are developed at sharp corners of the rocker arm both on the HDPE rocker arm and the chrome alloy steel rocker arm. A side by side comparison of stress values have been given for both the chrome alloy steel and composite rocker arms in table below. For such a loading system of the rocker arm it is seen that there is very less difference in the stress values between steel and composite.

Table 3: Stresses of steel rocker arm

Von Mises Stresses	Node number	Value in Pa
Maximum	1039	1.6×10^9
Minimum	1566	4.7×10^5

Table 4: Stresses of HDPE composite rocker arm

Von Mises Stresses	Node number	Value in Pa
Maximum	727	7.9×10^{10}
Minimum	27577	2.9×10^7

The results are also depicted in the following figures. Detailed results which will show the deformations and other parameters like the factor of safety and displacements from the finite element analysis will be shown in the reports that will accompany this document.

Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	467503 N/m^2 Node: 1566	1.57675e+009 N/m^2 Node: 1039

Model name: fea rocker arm steel
Study name: Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 119.769

von Mises (N/m^2)

1,576,750,336.000
1,445,393,408.000
1,314,036,480.000
1,182,679,552.000
1,051,322,752.000
919,965,824.000
788,608,960.000
657,252,032.000
525,895,104.000
394,538,208.000
263,181,312.000
131,824,408.000
467,503.188

Yield strength: 172,339,000.000

fea rocker arm steel-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.0038326 mm Node: 26711	0.0368149 mm Node: 1481

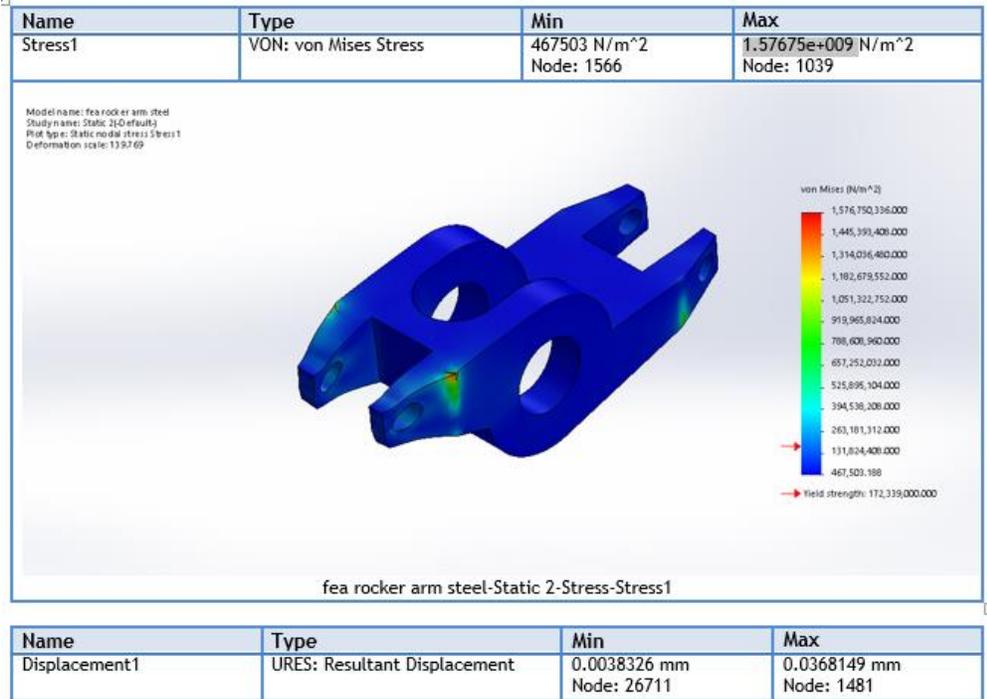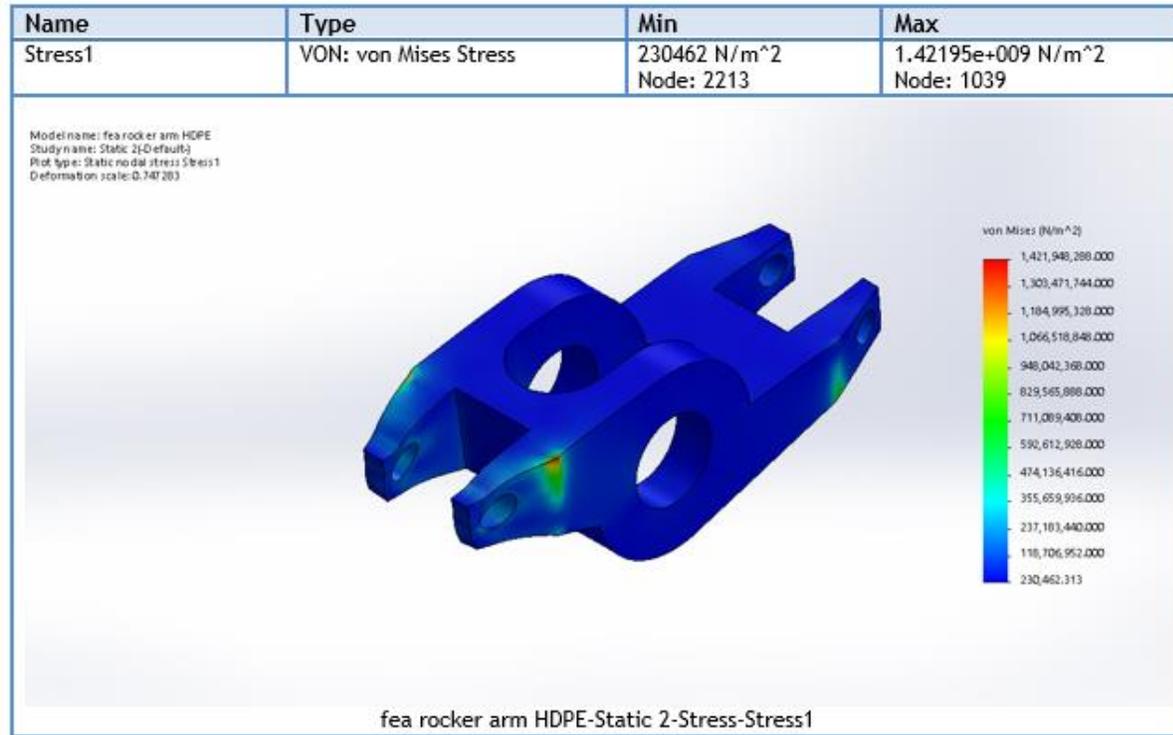**Figure 3: Results of the rocker arm simulation done by Solid Works software with static stresses**

Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	230462 N/m^2 Node: 2213	1.42195e+009 N/m^2 Node: 1039

Model name: fea rocker arm HDPE
Study name: Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 0.747283

von Mises (N/m^2)

- 1,421,948,288.000
- 1,303,471,744.000
- 1,184,995,328.000
- 1,066,518,848.000
- 948,042,368.000
- 829,565,888.000
- 711,089,408.000
- 592,612,928.000
- 474,136,416.000
- 355,659,936.000
- 237,183,440.000
- 118,706,952.000
- 230,462.313

fea rocker arm HDPE-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.697812 mm Node: 26711	6.89514 mm Node: 1481

Figure 4: Results of the rocker arm simulation done by Solid Works software with static stresses 2

Table 5: Comparison of the yield strength and the Von Misses Stresses

Parameter	Chrome steel alloy rocker arm	HDPE rocker arm
Yield strength	1.72x10^8 N/m^2	2.21x10^7 N/m^2
Von Mises Stress	4.7x10^5 N/m^2	2.30x10^5 N/m^2

4.2 Analysis

From the above studies it is observed that a light weight and reasonably high strength composite of Glass/HDPE can be used as rocker arm. Even at rigorous loading conditions the composite rocker arm can withstand the load equivalent to that sustained by a steel rocker arm which is still in use. It is also observed that the Von Misses stresses are less than the yield strengths hence the materials will not fail under the conditions applied, except for the sharp edges which are experiencing higher than normal stresses.

5.0: Recommendations and optimising
5.1 Recommendations and conclusion
With the results of the chrome alloy steel and the composite rocker arm completed the next step was to analyse the rocker arms with the goal of optimizing the part. Since there is a large stress concentration the sharp edges of the rocker arms this cut will be eliminated and the neck of the rocker arm will be smoothed out. Given the results and observations we got we concluded that the stresses developed in the composite is well within the limits without failure. Therefore the proposed composite may be considered as an alternate material for steel to be used as rocker arm.

References

Chung, C.-S. & Kim, H.-K., 2010. Safety evaluation of the rocker arm of a diesel engine. *Journal of Materials & Design,* 31(2), pp. 940-945.

Gagg, C. R. & Lewis, P. R., 2009. *In-service fatigue failure of engineered products and structures – Case study review. Eng. Fail. Anal.* s.l.:s.n.

Husain, S. M. & Prof Siraj, S., 2013. ROCKER ARM: - A REVIEW. *International Journal of Innovative Research in Science, Engineering and Technology,* 2(4), pp. 1120-1126.

Maoveni, S., 1999. *Finite Element Analysis Theory and Applications with ANSYS.* New Jersey: Prentice Home International.

Mishra, A., 2014. Stress Analysis of Glass/HDPE Composite Rocker Arm by Finite Element Method. *International Journal of Engineering Science and Innovative Technology,* 3(3), pp. 212-218.

Palomaki, E. & Hoffman, K., 2003. *Stock rocker versus roller rocker,* New York: s.n.

Palomaki, E. & Hoffman, K., 2003. *Stock Rocker vs Roller Rocker,* New York: Rensselaer Polytechnic Institute.

Yu, Z. W. & Xu, X. L., 2006. Failure analysis of diesel engine rocker arms. *Engineering Failure Analysis,* 13(4), pp. 598-605.

Biography

Tawanda Mushiri received the B.Sc. (Hons) in Mechanical Engineering and M.Sc. Manufacturing Systems and Operations Management degrees from University of Zimbabwe in 2008 and 2012, respectively. During 2008 – 2010, he went on to do a Graduate Trainee Learner ship from Oil Company under the Ministry of Energy and Power Development in Zimbabwe. He also worked as a Graduate Teaching Assistant at Chinhoyi University of Technology from 2011 to early 2013 teaching machine intelligence and advanced control and robotics. He is now a lecturer at the University of Zimbabwe from March 2013 to date teaching Engineering dynamics and design. He is a PhD student at the University of Johannesburg doing automation.

Charles Mbohwa's research activities and interests are in logistics, supply chain management, life cycle assessment and sustainability, operations management, project management and engineering/manufacturing systems management. His current Google Scholar h-index is 6 and Scopus h-index is 5. Currently is the Vice Dean of Research at University of Johannesburg and a full professor.