A feasibility study of plastic as an alternative to air package in performance vehicle

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Abstract: Blowing tires are far more than just distress. The Government body National Highway Traffic Safety Administration (NHTSA) estimates 733 fatalities in 2016 alone and at least 11,000 tire-related crashes arise every year, also not all of these were a result of a burst tire, but unquestionably they contribute. This analysis aims to replace packaging materials like air with different non-explosive medium. In this analysis, plastic is the priority material as there is an abundance of plastic on earth and we need to manage the extensive use of plastic. Every year 380 million tons of plastic get wasted. In this analysis, we are considering a Formula one tire which is a sport of extensive engineering and ideas. Only static structural analysis is carried as a lack of resources of manufacturing a special type of plastic which again is the other way around then of reducing the pollution. The model of the wheel was prepared according to the rules stated by the FIA in SOLIDWORKS 2016. The necessary calculations include reaction forces, mass-energy conversions and bending moments. The model was analysed for two materials which are air and polyethylene. The virtual simulation and structural analysis were performed using ANSYS workbench. Some of the important parameters which were considered for analysis are the order of an element, mesh size and mesh type. Both the air and polyethylene simulation results were compared and a convergence graph is plotted to check the results of deformation with varying element sizes.

1. INTRODUCTION

A tire burst occurs mainly due to the rapid dropping of pressurized air from the tire. When the structural integrity of the tire is compromised, it is unable to hold on to all that air inside. Due to this the pressurized air escapes by tearing through the tire rapidly causing an explosion. There are several reasons for tire bursts such as Improper inflation, High Temperatures, Overloading, Over-speeding, Low-quality tires. In this paper, we are trying to find the optimum materials to insert inside a tubeless tire which does not cause tire burst. Simultaneously we are keeping plastic as our priority because of the pollution caused by it in our day to day life. Pneumatic tubes use pressurized air to make sure that the contact patch between the ground and wheels are maintained and some part of the bump forces are absorbed [1]. Since air is used safety hazards are drastically reduced as it is inflammable and leakage does not affect the environment. But it comes with its problems of deflation and increased pressure during summer may lead to tire bursts. The main problem associated with pneumatic tires is Puncture. To overcome this problem, tubeless tires have been invented. These tires are a lot safer than the former when it comes to safety. These tires do not suddenly deflate when punctured. Tubeless tires are mainly used in performance vehicles [2] but in the case of off-road, its utility nears to nothing [3]. These tires are relatively heavier and also costlier than the former [4]. The tubeless tires have to be replaced after a fewer amount of repair and hence require higher maintenance. They also have no damping properties as such. Hence to solve the above-mentioned properties without affecting the...
overall performance, polyethylene plastic has been used. Plastic has very good damping properties and is a low-density material. The use of plastic contributes to the overall strength and stiffness of the tire [5].

1.1 Wheel
A circular looking block made up of a durable and hard material that has a bored hole through which an axle is passed and is rotated about the same center when torque is applied to it is called a Wheel. A typical tire model shown in figure 1.

![Figure 1. A Formula 1 style wheel](image)

2. PROBLEM STATEMENT

Wheels are the main invention which assisted mankind to transport heavy loads from place to place. Earlier logs were used. With recent inventions, tires of rubber have been designed and made lightweight by the use of Pneumatic tires. But the use of Pneumatic tires comes with its shortcomings like three Bursts, deflation, etc. Additionally, plastic has also become a threat to modern-day society. To tackle both the problems we have chosen to replace the traditional Pneumatic tires with plastic mainly polyethylene. Plastic is a material of low density and also has damping properties.

3. METHODOLOGY

A step by step procedure was carried out from design to simulation using tools like Solid works and ANSYS.

3.1 Design of Wheel
The initial step involved in the material selection covers the details of material properties as shown in table 1.

![Table 1. Material Properties](image)

| Properties      | Air         | Polyethylene |
|-----------------|-------------|--------------|
| Density         | 1.14 kg/m³  | 920 kg/m³    |
| Youngs modulus  | 0.5 Pa      | 82000 Pa     |
| Poisson ratio   | 0.2         | .49          |

Both the materials can be used as packaging material, although the most commonly used material medium is Air with the primary reason being ease of availability, less density and cost-effective.

3.1.1 3D modelling
Based on the dimensions provided by the FIA, the model was built in Solidworks using features like extrude, extrude cut and revolve. The solid modeling covers hump structure along with tire and axel
as shown in figure 2.

![Solidworks model of wheel with the packaging](image)

**Figure 2.** Solidworks model of wheel with the packaging

### 3.2 Determining load and boundary conditions

- Impact force
- Lateral force
- Compression/radial
- Tangential force
- Coefficient of friction between tire and concrete = 0.2
- Cycle time = 0.5 sec
- Force applied by the hump on to the tire = 500 N

Analytical calculation formula

“Low Pressure” passenger car tires formula:

\[
L = 6.65 \times P^{0.585} \times S^{1.702} \times [(D_R + S)/(19+S)]
\]

\[
L/P^n = L_0/P_0^n
\]

Where 'n' is 0.585 since the relation would not be a linear one

Where:

- \(L\) = tire load carrying capacity at pressure \(P\)
- \(P\) = tire inflation pressure
- \(S\) = tire section width (on rim width = 62.5% of tire section width)
- \(D_R\) = nominal rim diameter

\[
L/P^n = L_0/P_0^n
\]
Equating (1) and (2)...

\[ \frac{L_0}{P_0} \cdot P^\alpha = 6.65xP^{0.585} \times S^{1.702} \times \left[ \frac{(D_r + S)}{(19+S)} \right] \]

\( P_0 \) can be calculated which is the required pressure.

4. SIMULATION STUDY

The succeeding approach was followed to solve the problem and the same was checked for both the materials during the analysis. In figure 3 its clearly being highlighted with inner portion of the tire completely filled with a polyethylene material.

4.1 Type of analysis

As we are not considering the non-linearity behavior of the tire, we are going forward with Static structural analysis as our major form of analysis. Figure 4 illustrate the project model in case of existing condition and polyethylene packaged.

4.2 Contact generation

The tire of the wheel is in no-slip condition (bonded), the rim and the tire are in contact (no separation) as shown in figure 5.
4.3 Mesh generation

Based on the element size, to analyze the convergence aspect it has been decided to mesh 20 to 30 mm size in step of 5mm. The following data were obtained for the 3 different cases of meshing as shown in figure 6 and table 2 with elemental and node number details.

| Element size | Tetragonal Elements | Tetragonal Nodes |
|--------------|---------------------|------------------|
| 30 mm        | 24872               | 39589            |
| 25 mm        | 39149               | 59790            |
| 20 mm        | 71437               | 105134           |

From the above statistics, it is an evident fact that a higher number of nodes and elements are obtained at finer element sizes (20 mm). The results obtained are more accurate when the number of nodes and elements is more. On the other hand, it takes more computational time when the numbers of nodes are more.

To improve and check the convergence of the results, two methods were used.
a) H-type: This method refers to the change in the global element size set during the meshing process either by increasing or decreasing the element size without changing the type of mesh used in simulations, which may or may not converge the results[6,7].

b) P-type: This method focuses on the mesh type used in the analysis keeping the element size the same, which means the order of the elements is changed. Higher-order implies more accurate results but takes noticeably more computational time[8,9].

Considering the change in mesh size deformation was observed and there was no noticeable change in deformation observed in 5 iterations over a range of 20mm to 30mm element size, hence that concludes that the results are converged.

The following types are used to infer regarding the convergence and accuracy, in this analysis, hence the H type method of convergence is been used.

4.4 Loading and boundary conditions
The calculated forces like bump force were applied by the road to the tire of the wheel with a force of 2500N and the analysis is carried out in the no-slip condition as shown in figure 7.

5. RESULTS AND DISCUSSION

According to the simulation study mentioned, the analysis was carried out in ANSYS workbench and the following results were obtained.

5.1 Static structural analysis
The individual analysis was carried out for the existing model and the proposed model with element size was 5mm to get the most efficient results in the stipulated amount of time. The Von-Mises stress, strain and deformation plots are as shown in figure 8, 9, 10 for air package as material for existing tire. Figure 11, 12 and 13 explain the von mises stress, strain and deformation plots for polyethylene as a material.
Case 1 – a) Stress plot

![Figure 8. Stress on tire with air package](image)

b) Strain plot

![Figure 9. Strain on tire with air package](image)

c) Total deformation plot

![Figure 10. Total deformation on tire with air package](image)
Case 2 – a) Stress plot

![Stress on tire with polyethylene package](image1)

**Figure 11.** Stress on tire with polyethylene package

b) Strain plot

![Strain on tire with polyethylene package](image2)

**Figure 12.** Strain on tire with polyethylene package

c) Total deformation plot

![Total deformation on tire with polyethylene package](image3)

**Figure 13.** Total deformation on tire with polyethylene package

The von-mises stress plot results seem to be accurate based on the convergence theory and compatibility equation which is decided based on the number of iterations carried out for each of the case [10, 11].
5.2 Comparison of the results for the packaging material

Table 3. Comparison results for packaging material

| Category       | Existing case | Proposed Case |
|----------------|---------------|---------------|
| Von-Mises      | 4.4438 MPa    | 0.6126 MPa    |
| Strain         | $1.37 \times 10^6$ | $7.62 \times 10^6$ |
| Total Deformation | 0.0736 micron | 0.0055 micron |
| Flexibility    | More          | Less          |
| Weight         | 0.00684 kg    | 5.52 kg       |

6. CONCLUSION

Analysis has been carried out on tire with both the materials to check the stresses on it and the deformation that occurs. Analysis has also been carried on the pneumatic tube without the tire to understand how it behaves during loading.

The yielded results were as expected and hence we were able to replace the Pneumatic tube with plastic (Polyethylene). Analysis has been done on Plastic to understand its behavior during similar loading conditions. The results were compared and the same has been displayed above in table 3. From the task, along with the results, it is possible to replace the traditional pneumatic tubes with the plastic. The stiffness of the plastic may increase the overall stiffness of the tire, but the problems of tire bursting, tire puncture, and deflation of the tires during summer could be avoided.

It also becomes significant in the long run as plastic disposable is a huge problem faced by modern society.

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