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Design of a Compressed Air Vehicle

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Abstract: Smart mobility solutions aid the growth of smart cities by creating a better quality of life and reducing its environmental footprint. Emissions from petrol- and diesel-powered vehicles are a major contributor to the deterioration of air quality around the world. In addition to this, rising fuel prices continue to take a heavy toll on the pockets of the working class. A favourable countermeasure to this predicament is the fabrication of a vehicle that takes advantage of the earth's most abundant resource "Air" as an energy source. The compressed air vehicle is an eco-friendly vehicle which works on air. This research work aims at designing a cheaper, more efficient and aesthetically appealing automobile while efficiently running on this renewable energy. The car model has been designed using the software solid works and tested on ANSYS workbench followed by rigorous trials to ensure its optimal performance and safety. The designed car can reach speeds ranging from 10-20 km/h while being eco-friendly and sustainable at the same time. This vehicle can be used for short distance applications such as golf carts, mall taxis etc.

Keywords: Compressed air, Renewable energy, Vehicle, SolidWorks, ANSYS

I. INTRODUCTION

The first vehicle that ran on compressed air was built in France by Louis Mekarski, a Polish engineer in 1870. It was patented in 1872 and 1873 and testing was conducted in Paris in 1876. The concept of this engine was to use the energy stored in compressed air to increase the gas enthalpy of hot water, when passed through hot water. In 1992, Armando Regusci a scientist from Uruguay constructed a four-wheeler powered by a pneumatic engine that went 100 kilometres on a single tank. The founder of the Luxembourg based MDI group and ex-F1 engineer Guy Negre developed the "Air Car" which is a vehicle that runs on a compressed air engine.Pure air which is available in abundance can be cheaply and efficiently be compressed making it one of the prime options to eradicate pollution. All attempts made so far have been to reduce pollution.

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Battery electric engines, Fuel cell engines and Hybrid electric engines are other alternatives that are in development. These aren't permanent solutions to the problem of pollution just transitional ones during the process of electricity generation, there are carbon emissions, water pollution and soil pollution due to the improper handling or disposal of batteries etc. Compressed air technology has various advantages over the above-mentioned engines as air is used as fuel, and the exhaust is also air, in this case pollution only occurs while generating the compressed air. At present, compressed air is used in vehicles to boost the initial torque. Turbo charging is a technique that is used to enhance the power and efficiencies of automotive engines that run purely on compressed air.

Andrew Papson et al. (2010) has studied the potential performance of compressed air vehicles with regards to parameters such as driving range, carbon footprint, fuel economy, fuel costs and assessed their compatibility as an alternative mode of transportation to petrol and electric vehicles. Analysis of the vehicles revolves around energy density of compressed air, thermodynamic losses of expansion, compressed air vehicle efficiency. The study shows that although the compressed air vehicle is an unorthodox convincing solution to meet the transportation needs of today, it is not very efficient and needs further development to be considered for everyday use. Vishwajeet Singh (2017) aimed to convert a 150 CC 4-stroke engine to a 2- stroke engine that could run with the energy of the air stored in the compressed air tanks. Several modifications were made to the engine such as timing gear of the cam shaft, inlet and valve timings. The major changes they made to engine include modifying the cam shaft in such a way that opened and closed at every 180° revolution of the crank shaft. They were successfully able to convert the 4-stroke engine into 2-stroke engine with the given modifications. Shubham Kumar et al. (2017) during their research were able to perform an in-depth analysis of the performance of the compressed air engine in each gear. They found out that the speed of the engine is directly proportional to the pressure. Furthermore, they were able to achieve an exhaust gas temperature between 20-25°C which is an added advantage considering the effects of IC engines on global warming. Manjunath B. A. et al. (2017) studied about the design and fabrication of a three wheeled air driven vehicle. They aimed to harness the potential of compressed air as an energy source. A piston type compressed air engine was used. Tests were performed at different open positions of the valve (full, three quarters and half) to determine the ideal position for compressed air to enter the engine. Post assessment they were able to conclude that of the three valve open positions, optimal power was generated at the fully open position. Also, the time taken by the vehicle to cover 10 meters was the least for this position of the valve. J. Purushothaman et al. (2017) in their design and development focused on getting a perfect valve position timing so that there is no loss of pressure in the cylinder and thereby improving the efficiency. They did modifications to the engine by modifying the cycle time of the cam follower. With this they were able to achieve a top speed of 30 km/hr. Yuan Wei-Wang et al. (2014) studied the applications of piston type compressed air engines in motor vehicles. A 100 CC 4 stroke IC engine was converted into a 2-stroke engine that could run on compressed air. The air pressure and intake valve timings were varied, and the different power outputs compared. This engine was fitted on a motorcycle which was able to reach a top speed of 38.2 km/h for a 5-kilometre range. One of the drawbacks of this project was the limited range making it a feasible option only for vehicles that cover short distances such as golf carts and ATVs. To extend the range it must be paired with a standard IC engine. S.S Verma (2013) in his research used compressed air stored in tanks to drive a reciprocating system. They claimed that their engine developed has an efficiency of up to 90% which is significantly more than IC engines.Hemant Kumar Nayak et al. (2013) studied and compared the properties of a compressed air vehicle to a regular gasoline powered vehicle and battery electric vehicle. They concluded that compressed air vehicles as well as battery electric vehicles are more efficient and eco-friendlier than fuel engines. For efficiency and power, the compressed air engine has the upper hand as it can be paired with a gasoline powered engine. Devang Marvania et al. (2016) discussed about the need for air powered technology in the automotive industry. The outline of a compressed air powered system is explained a long with its implementation and how it measures up to other technologies. They concluded that compressed air vehicles have a relatively lower range and higher cost of driving compared to gasoline and electric vehicles. A pneumatic hybrid was proposed as a more practical alternative for long distance applications. However, this technology would suit situations that require short range and low speeds. Lin Liu et al. (2007) investigated the practicality of vehicles powered by compressed air and liquid nitrogen. Fuel economy, energy density, safety etc. were evaluated based on experimental data and a thermodynamic analysis. The energy density of liquid nitrogen and compressed air were found to be similar. From this study, it was inferred that although compressed air engines are inferior to IC engines and require large storage tanks, they have a better overall efficiency and can be a reasonable option if developed as a hybrid.

Pokala Saiprasanna Kumar et al. (2017) proposed a compressed air vehicle which runs on a pneumatic motor. They have chosen a vehicle driven by three wheels and comparison is made between different arrangement of the wheels. At the end of the research the scope of improvement is the usage of heat exchangers to combat the temperature differences during expansion and compression and usage of activated charcoal for saving energy. It concludes that the CAV is an eco-friendly, easy to drive and cheap alternative, but its speed and mileage is limited but could be improved with further research. Saurabh Pathak et al. (2014) researched on the benefits and short comings of using pneumatic vehicle as a permanent solution in replacing combustion engines. At the end of their research they were able to conclude that a vaned novel air turbine could be used as the losses were minimal and efficiency between 72% -97%

Mihai Simon (2017) aimed to use electrical energy to compress nitrogen gas in cylinder that would in turn drive the mechanism. By heating nitrogen in an atmospheric heat exchanger and absorbing heat from outside air and using the pressurised air to drive the engine. Tank of 10-25 litre capacity was used at 10 bar pressure. The principle behind this project was to transform the surplus electrical energy generated from solar and wind power into compressed nitrogen gas. After testing the vehicles, it was found to reach a maximum velocity of 60 km/h when running at its optimal speed of 43 km/h the vehicle covered 6150 m.

Rixon K. L. et al. (2016) fabricated a compressed air bike. A turbine was used to produce mechanical work by using the energy from compressed air. The turbine shaft was connected to the rear wheel via a gear arrangement to transmit motion. To maintain a constant pressure and volume of compressed air, a shock absorber and air pressure amplifier were attached to the air storage tank. This is turn improved the overall efficiency of the bike.

II. METHODOLOGY

The chassis of the compressed air vehicle has been modelled using SolidWorks 2017. The suspension has been modelled using Creo 5.0. The analsyis has been perfomed using ANSYS 16.0 in order to check if the vehicle is safe and stable.

III. DESIGN OF CHASSIS AND SUSPENSION

Figure 1 shows the 3D model of the chassis which was created using SolidWorks, Figure 2 and figure 3 shows the rear suspension and front suspension modelled using Creo.

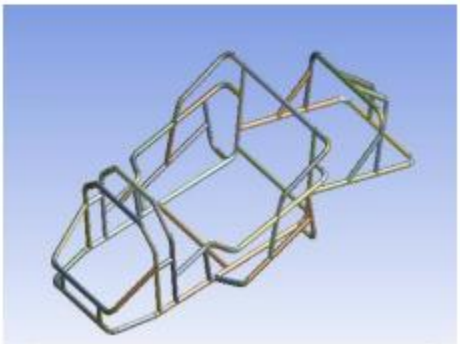

Fig. 1 – 3D Model of the Chassis

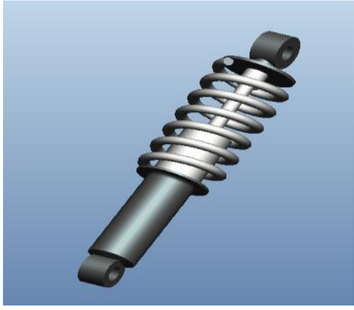

Fig. 2 Rear Suspension Fig. 3 Front Suspension

IV. CHASSIS ANALYSIS

The chassis analysis has been performed using ANSYS 16.0. A front impact test was performed by applying a force of 138.88 N. This force was calculated considering the mass of the vehicle to be 250 Kg and the acceleration was calculated based on the desired velocity and the time taken to achieve this. Fig. 4 shows the front impact test, from this figure it is observed that the blue portions on the sketch represent the fixed supports, whereas the red portion shows the place at which the load is applied. Fig. 5 shows the total deformation during the front impact test of the vehicle. From this figure it is observed that the maximum deformation was 0.0881 mm and it was observed at the front portion of the chassis. From this it is observed that the deformation was very small and hence it is negligible. Fig. 6 shows the equivalent elastic strain and from this figure it is observed that the maximum elastic strain was 0.000115 and it was observed at the left corner of the chassis. From this it can be concluded that the elastic strain was very less and hence can be neglected. Fig. 7 and Fig. 8 shows the equivalent stress and the normal stress for the front impact test and from this figure it is observed that the maximum stress is 23.04 MPa and the normal stress is 11.49 MPa. The equivalent stress and normal stress have been calculated in order to check the factor of safety. From this it is observed that the factor of safety was greater than 1 and hence the front impact test was safe and stable.Fig. 9 to Fig. 13 shows the boundary conditions, total deformation, equivalent stress, equivalent elastic strain and normal stress for the side impact test. From these figures it is observed that, the total deformation was 0.935 mm and equivalent stress was 134.3 MPa. Also, the elastic strain was 0.00067 and normal stress was 68.147 MPa. From this it can be concluded that the deformation was very less, and the factor of safety was greater than one which clearly indicates the side impact test is safe and stable.

1. Front Impact Test

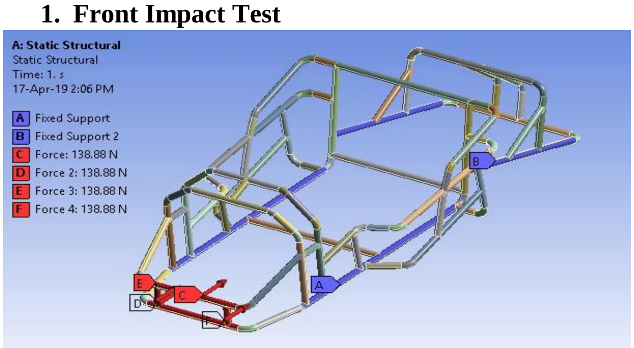

Fig. 4 Front impact Boundary conditions

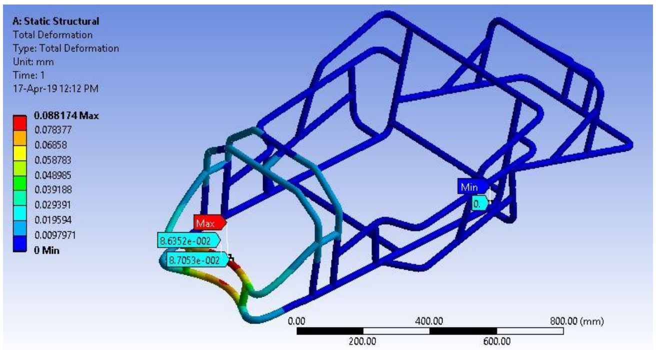

Fig. 5 Total Deformation

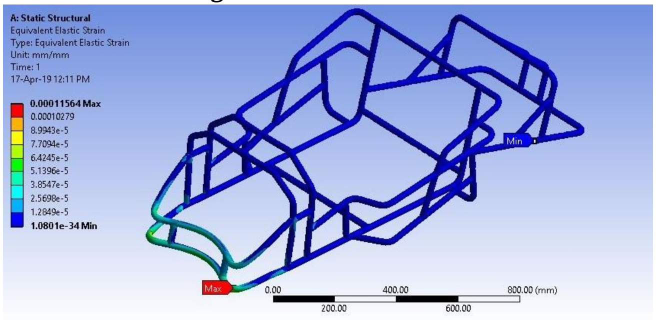

Fig. 6. Equivalent Elastic Strain

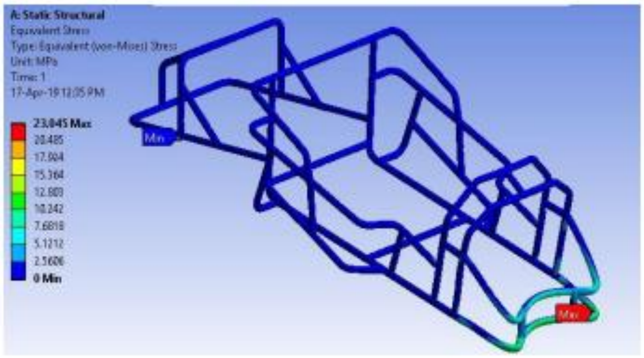

Fig. 7 Equivalent stress

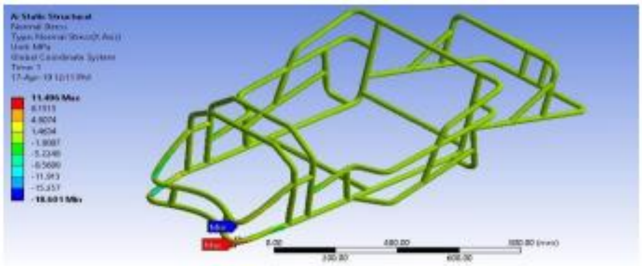

Fig. 8 Normal stress

2. Side Impact Test

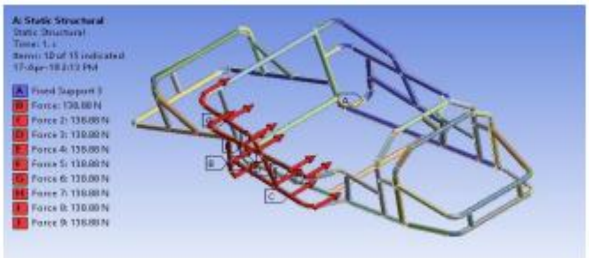

Fig. 9 Boundary Conditions for side impact

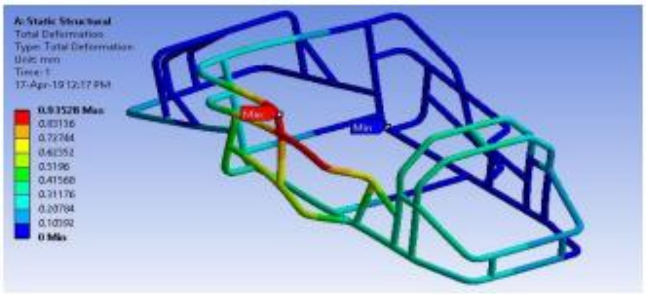

Fig. 10 Total deformation

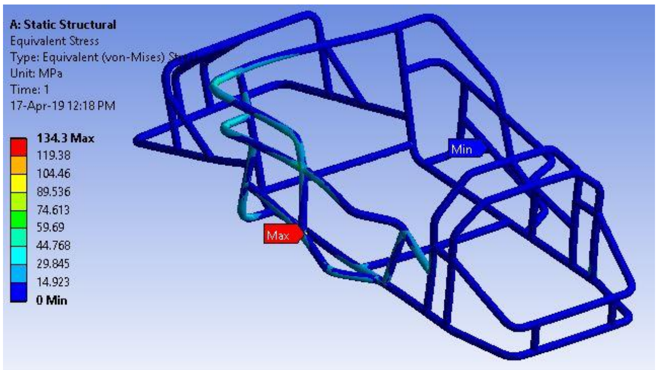

Fig. 11 Equivalent Stress

Fig. 12 Equivalent Elastic Strain

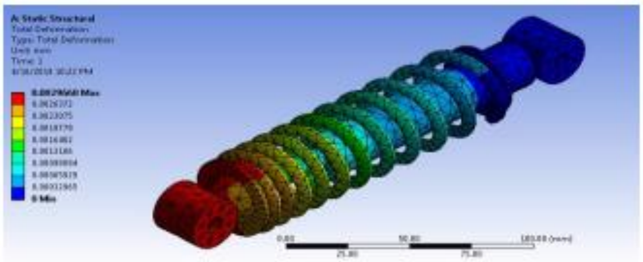

Fig. 13 Normal Stress

V. SUSPENSION ANALYSIS

The analysis has been done for both the front and rear suspensions considering a load of 490.5 N. This load was estimated by considering the mass of the vehicle as 250 Kg and acceleration due to gravity. Fig. 14 shows the boundary conditions of the front suspension in which one side is held fixed and the other side is subjected to the above said load. Fig. 15 shows the total deformation in which the maximum deformation observed was 0.00296 mm which is very less. Fig. 16 shows the equivalent stress and from this figure it is observed that maximum equivalent stress was 6.713 MPa and observed at the damping portion of the loading side. This clearly shows that the stresses are maximum and are transmitted from the wheel towards the upper portion of the vehicle. Fig. 17 shows the normal stresses and from this figure it is observed that the maximum normal stress was 1.262 MPa. From Fig. 16 and Fig. 17 it is observed that the factor of safety was greater than 1 and the front suspension is safe and can withstand the applied loadAfter the front suspension, the rear suspension was analysed for the same parameters and Fig. 19 to Fig. 23 shows the boundary conditions, total deformation, equivalent stress, equivalent elastic strain and normal stresses. The rear suspension also behaves in a similar fashion to the front suspension and the factor of safety was greater than 1, which clearly demonstrates that the suspension can withstand the applied load.The results of the analysis as well as the comparison of total deformation, equivalent stress, equivalent elastic strain, normal stress and factor of safety for both front and side impact test as well as front and rear suspensions have been tabulated in Table 1 and Table 2.

1. Front Suspension

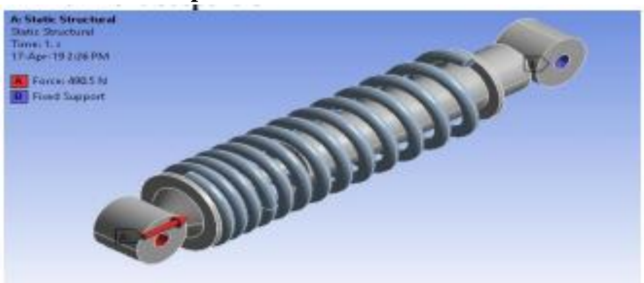

Fig. 14 Front Suspension Boundary Conditions

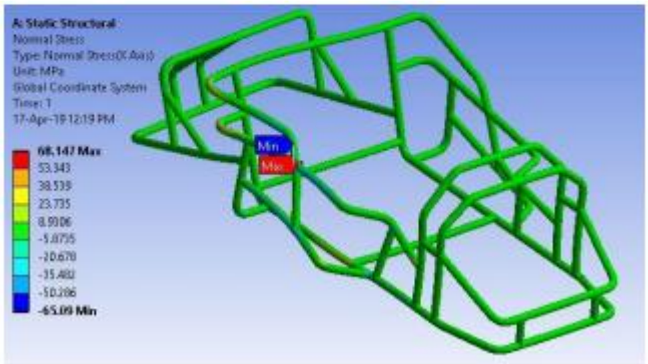

Fig. 15 Total Deformation

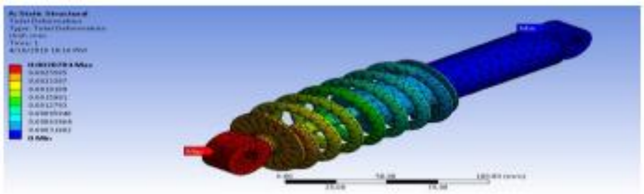

Fig. 16 Total Deformation

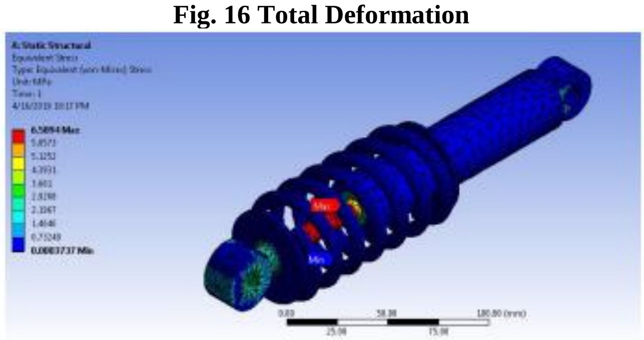

Fig. 17 Equivalent Stress

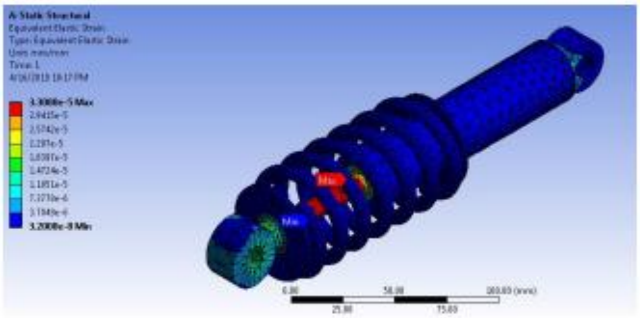

Fig. 18 Normal Stress

2. Rear Suspension

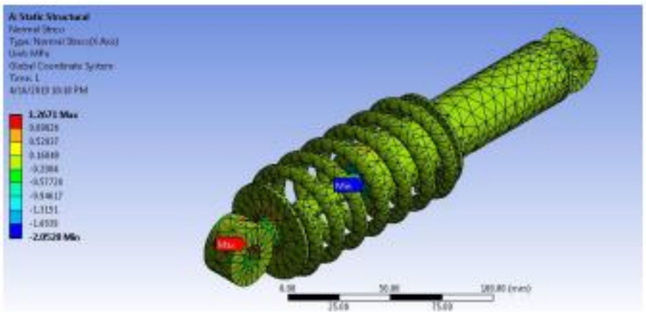

Fig. 19 Equivalent Elastic Strain

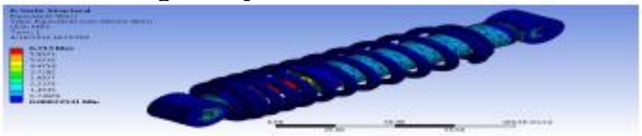

Fig. 20 Rear Suspension Boundary Conditions

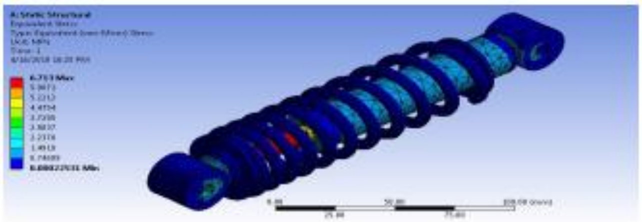

Fig. 21 Total Deformation

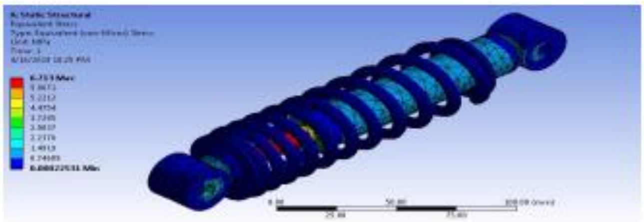

Fig. 22 Equivalent Stress

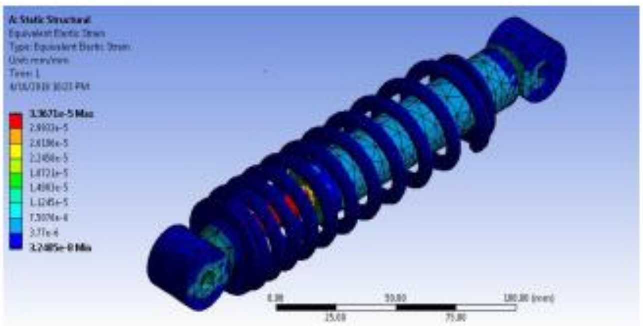

Fig. 23 Equivalent Elastic Strain

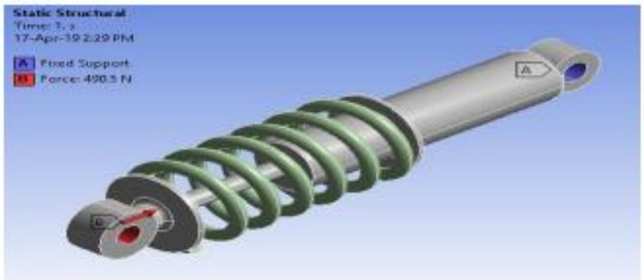

Fig. 24 Normal Stress

Table 1. Results for Front and Side Impact Tests

	Front	Rear
Total Deformation (mm)	0.0029668	0.0028784
Equivalent Stress (MPa)	6.713	6.5894
Equivalent elastic Strain (mm/mm)	3.3671 x 10^{-5}	3.3088 x 10^{-5}
Normal Stress (MPa)	1.2629	1.2671
Factor of Safety	>1	>1

VI. RESULT AND DISCUSSION

After The Completion Of The Analysis For The Chassis And Suspensions, Graphs For The Front Impact Test (Fig. 24 To Fig. 28) And Side Impact Test (Fig. 29 To Fig. 33) Were Plotted By Considering Forces Ranging From 100 N To 500 N And The Corresponding Values Of Equivalent Stress, Total Deformation, Normal Stress And Factor Of Safety. Also, Graphs Have Been Plotted By Comparing Equivalent Stress And Equivalent Elastic Strain. From These Figures It Is Observed That As The Force Increases, The Equivalent Stress, Normal Stress And Total Deformation Increases. Also, With An Increase In Equivalent Stress, There Is An Increase In Equivalent Elastic Strain. However, There Is A Decrease In The Factor Of Safety As The Applied Force Increases. From All Of The Above Parameters It Can Be Clearly Stated That The Chassis And Suspension Is Safe

1. Front Impact Test

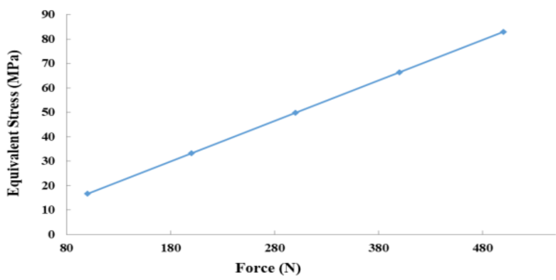

Fig. 25 Equivalent Stress Versus Force

Table 2 Results for Front and Rear Suspensions and stable.

	Front	Side
Total Deformation (mm)		
Equivalent Stress (MPa)	23.045	134.3
Equivalent elastic Strain (mm/mm)	0.00011564	0.00067721
Normal Stress (MPa)	11.496	68.147
Factor of Safety	>1	>1

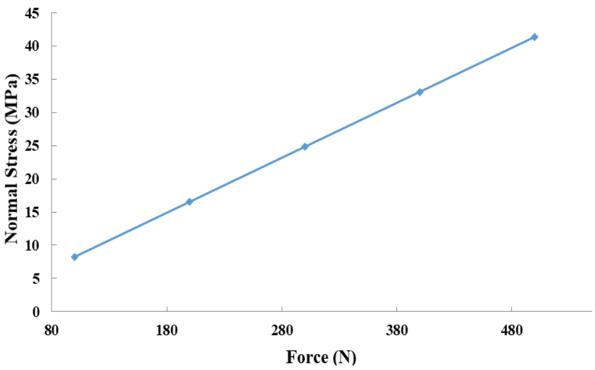

Fig. 26 Normal Stress versus Force
Fig. 29. Equivalent Stress vs Force

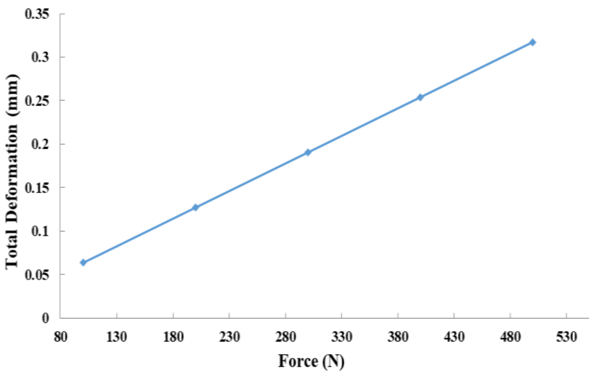

Fig. 27 Total Deformation versus Force

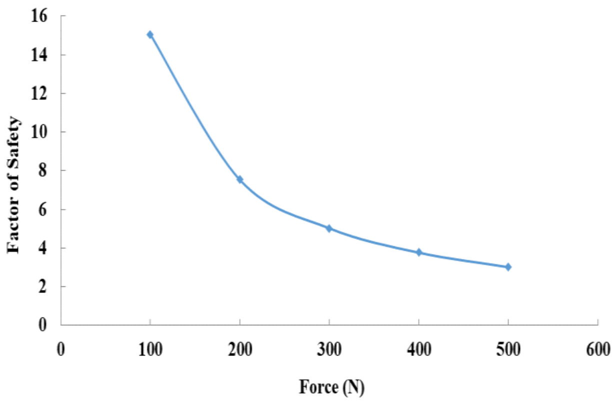

Fig. 28 Factor of Safety versus Force

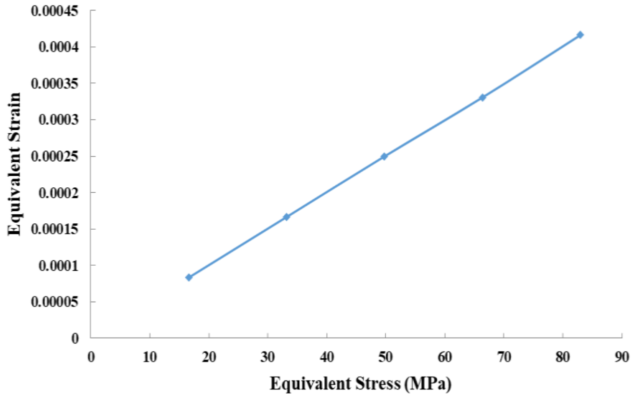

Fig. 29 Equivalent Stress versus Equivalent Strain

2. Side Impact Test

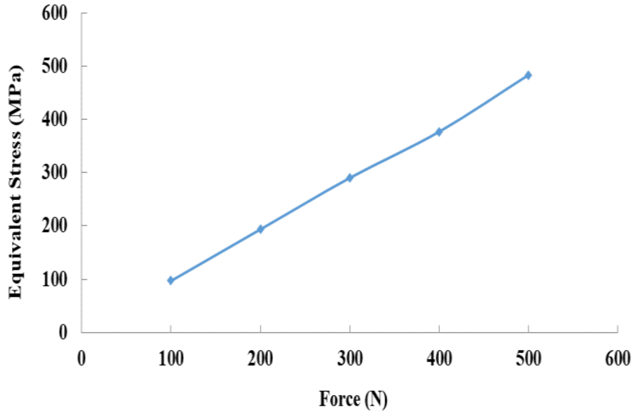

Fig. 30 Equivalent Stress versus Force

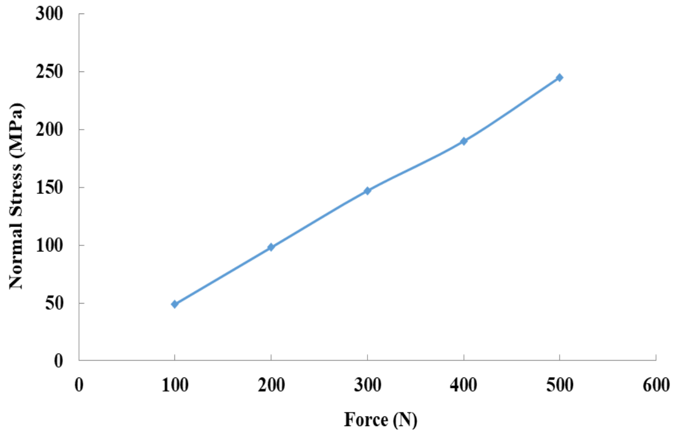

Fig. 31 Normal Stress versus Force

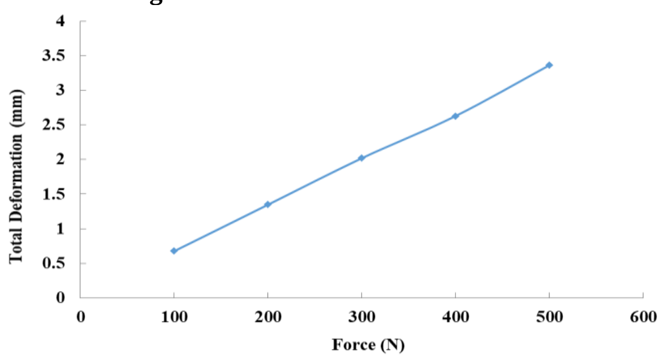

Fig. 32 Total Deformation versus Force

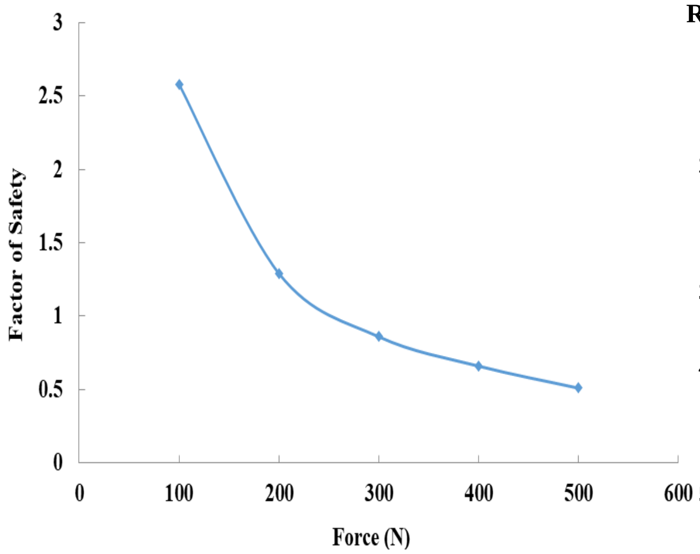

Fig. 33. Factor of Safety vs Force

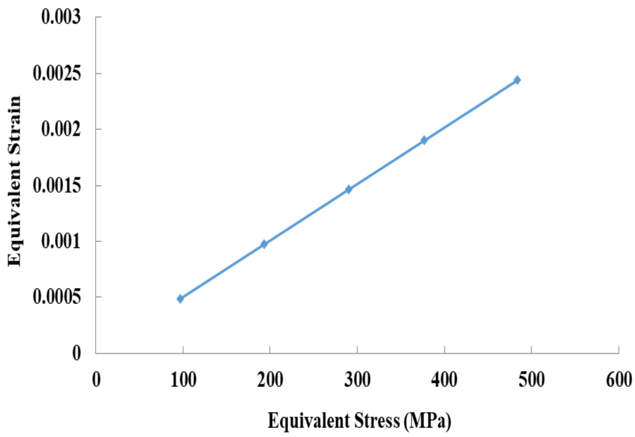

Fig. 34 Equivalent Strain versus Equivalent Stress

VII. CONCLUSION

The design of a compressed air vehicle using SolidWorks, Creo and analysis using ANSYS have been performed in this paper in order to understand whether the vehicle is safe for operation. From this analysis the following conclusions can be drawn.

- The front and side impact test of the chassis considering total deformation, equivalent stress, normal stress and equivalent elastic strain shows that the designed air compressed vehicle is within the safe limits in case of a collision.
- The front and rear suspension analysis shows that the compressed air vehicle can withstand the load and can be safely operated.
- Based on chassis and suspension design it can be stated that factor of safety was greater than one and from this it can be concluded that the design is safe and stable.

Based on the analysis it can be concluded that the design of the vehicle is safe from the analysis point of view.

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