International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
National Conference on
Recent Trends in Mechanical Engineering (NCRTIME2K19)
Volume 5, Special Issue 07, June-2019.

DESIGN AND ANALYSIS OF HEAVY VEHICLE REAR AXLE

[1]M.Mahendra Babu, B. Sai Kumar, Sk. Shahid, M. Bharath, C. Siva Tharun
[1]Associate Professor, UG Student
, Dept of M.E, Geethanjali Institute of Science & Technology, Nellore

ABSTRACT

An axle is a central shaft for a rotating wheel. On wheeled vehicles, the axle may be fixed to the wheels, rotating with them, or fixed to its surroundings, with the wheels rotating around the axle. The axles serve to transmit driving torque to the wheel, as well as to maintain the position of the wheels relative to each other and to the vehicle body. The axles in a system must also bear the weight of the vehicle plus any cargo. The rear axle beam is one of the major parts of vehicle suspension system. It houses the whole back load assembly. About 35 to 65 percent of the total vehicle weight are taken up by the rear axle.

Hence proper design of the rear axle beam is extremely crucial. In present research work design of the rear axle of heavy commercial vehicle were done. The approach in this project has been divided into two steps. In the first step, rear axle will be designed in CREO software later the model is imported into ANSYS for results. In the second step, the model is assigned with four different materials and the analysis results for the materials are compared to conclude a suitable material for a rear axle manufacturing.

KEYWORDS:

Modeling, Meshing, Analysis, Comparison of Results.

CHAPTER 1

INTRODUCTION

An auto industry is one of the important and key sectors of the Indian economy. The auto industry includes of automobile sector, auto components sectors and includes commercial vehicles, passenger cars, multi-utility vehicles, two wheelers, three wheelers and related auto parts. The demands on the automobile designer increased and altered rapidly, first to meet system safety needs and later to reduce weight so as to satisfy fuel economy and vehicle performance requirements.

Engine location important to provide greater stability and safety at high speeds by lowering the centre of gravity of the road vehicles; the complete centre portion of the axle is dropper. Rear axles are subjected to both bending and shear stresses. In the static condition, the axle might be considered as beam supported vertically upward at the ends (at the centers of the spring pads under the dynamic conditions, vertical bending moment is increased due to road roughness. Thus it is very difficult to find the crack propagation in short time. So it is necessary to incorporate finite element methodology. During the operation on vehicle, road surface irregularity causes cyclic fluctuation of stresses on the axle, which is the main load carrying member.

Therefore it is necessary to make sure whether or not the axle resists against the fatigue failure for a predicted service life. Axle experiences completely different loads in different direction, primarily bending load or vertical beaming due to curb weight and payload, torsion, due to drive torque, cornering load and braking load. Rear axle will experience a 3G load condition when the vehicle goes on the bump.

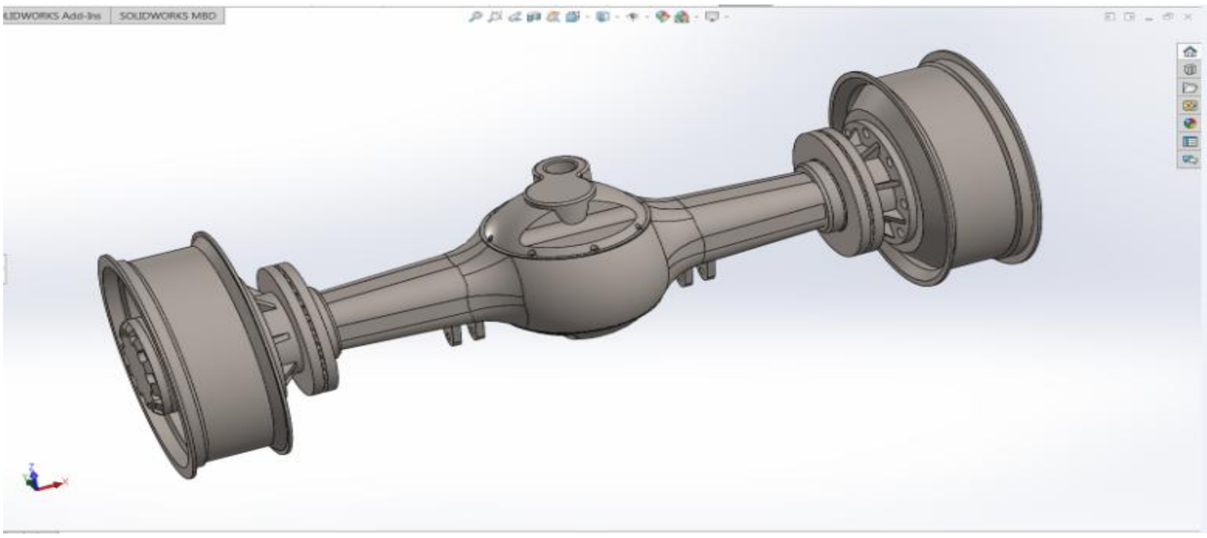
Performing physical test for vertical beaming fatigue load is expensive and time consuming. So there is a necessity for building FEA Models which may virtually simulate these loads and can predict the behavior. Even though the FEA produce fairly accurate results, solution accuracy heavily depends on accuracy of input conditions and overall modeling methodology used to represent the actual physics of problem.

Therefore validation of FEA model is of utmost importance. Typically FEA model is validated by correlating FEA results analytical design. Hence correct design of the front axle beam is very critical. The approach in this paper has been divided into two steps. In the first step analytical method used to design front axle.

For this, the vehicle specifications, its gross weight and payload capacity in order to find out the stresses and deflection within the beam has been used. In the second step rear axle were modeled in Pro-e. The cad model was solved in ANSYS software system. The FEA results were compared with analytical design.

CONSTRUCTION AND OPERATION:

The axles achieve to transmit driving torque to the wheel. Also it can maintain the position of the wheels relative with each other and to the vehicle body. The axles must additionally bear the weight of the vehicle plus any cargo. The rear axle beam is one of the main parts of vehicle suspension system shown in figure. It houses the rear assembly. Rear axle is made of I-section in the middle portion and circular or elliptical section at the ends.



The special section of the axle makes it able to withstand bending loads due to weight of the vehicle and torque applied due to braking. It consists of main beam, stub axle, and swivel pin, etc. The wheels are mounted on stub axles.

REAR AXLE AND STEERING SYSTEM:

Rear axle carries the weight of the rear part of the automobile and absorbs shocks due to road surface variations. The rear axles are generally live axles. The chapter discusses the rear axle construction and its alignment.

LOAD DETERMINED DESIGN:

The first consideration when designing an automotive suspension is that the part assembly is subject to both static loads (applied by the car's stationary weight) and dynamic loads (those created while driving) corresponding to tension, compression and shear forces distributed in all three spatial axes: longitudinal, vertical and lateral. The dynamic forces imposed while driving can be up to five times greater than the car's static load; thus dynamic loads are the determining factors in the part's critical structural dimensions and overall design, Florentz says. Hutchinson's preliminary "macro" design solution to the problem of these multiaxial loads was to simulate the primary suspension structure with a beam-homogenized orthotropic model.

The beam orthotropic model served as a "baseline" that allowed engineers to target the localized stiffness properties necessary to meet the vehicle's basic static load. A material is orthotropic if its mechanical or thermal properties are unique and independent in three mutually perpendicular directions, as opposed to an isotropic material in which the properties are the same in all directions. Additionally, a material can have a homogeneous or non-homogeneous microstructure. A material such as rolled steel is naturally orthotropic and homogeneous. Designing a homogeneous orthotropic composite is a matter of constructing a laminate with the same "micro-structure" (i.e., materials, in this case, an epoxy resin) with a majority of unidirectional glass fibers, in a layup constituting varying thicknesses and directions. Such a structure would allow design engineers to account for various distortions and loads in each of the three independent axes by adding or subtracting reinforcement in specific areas after the part had been modeled in finite element analysis (FEA). Accordingly, the second step in the design process was the detailed finite element model (FEM) simulation of the suspension at the Hutchinson Research Centre.

Chassis

A **chassis** consists of an internal vehicle frame that supports an artificial object in its construction and use, can also provide protection for some internal parts. An example of a chassis is the underpart of a motor vehicle, consisting of the frame (on which the body is mounted). If the running gear such as wheels and transmission, and sometimes even the driver's seat, are included, then the assembly is described as a rolling chassis.

Vehicle Frame

A **vehicle frame** is the main supporting structure of a motor vehicle to which all other components are attached, comparable to the skeleton of an organism.

Functions:

The main functions of a frame in motor vehicles are:

1. To support the vehicle's mechanical components and body
2. To deal with static and dynamic loads, without undue deflection or distortion.

These include:

- Weight of the body, passengers, and cargo loads.
- Vertical and torsional twisting transmitted by going over uneven surfaces.
- Transverse lateral forces caused by road conditions, side wind, and steering the vehicle.
- Torque from the engine and transmission.
- Longitudinal tensile forces from starting and acceleration, as well as compression from braking.
- Sudden impacts from collisions.

Types of frame according to the construction:

- Ladder type frame
- X-Type frame
- Off set frame
- Off set with cross member frame
- Perimeter Frame

CREO:

CREO is mechanical design software. It is a feature-based, parametric solid modeling design tool that takes advantage of the easy-to-learn Windows graphical user interface. You can create fully associative 3-D solid models with or without constraints while utilizing automatic or user-defined relations to capture design intent. CREO has advantages of giving accurate results. 3-D modeling, however, produces more accurate results on all but the fastest computer computes effectively.

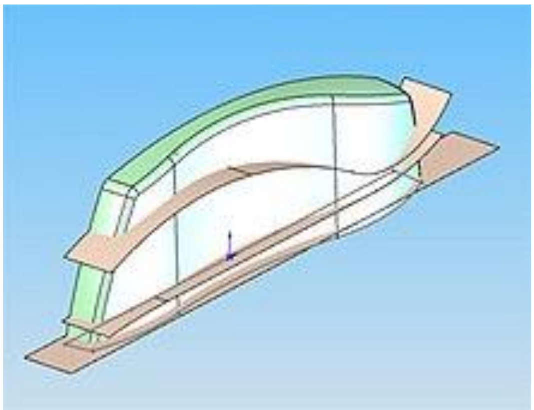
SOLIDWORKS

SolidWorks is a solid modeler, and utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on Parasolid-kernel.

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allows them to capture design intent.

Design intent is how the creator of the part wants it to respond to changes and updates. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. SolidWorks allows the user to specify that the hole is a feature on the top surface, and will then honor their design intent no matter what height they later assign to the can.

Features refer to the building blocks of the part. They are the shapes and operations that construct the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as bosses, holes, slots, etc. This shape is then extruded or cut to add or remove material from the part. Operation-based features are not sketch-based, and include features such as fillets, chamfers, shells, applying draft to the faces of a part, etc.



screen shot captured from a SolidWorks top-down design approach.

Building a model in SolidWorks usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

In an assembly, the analog to sketch relations are mates. Just as sketch relations define conditions such as tangency, parallelism, and concentricity with respect to sketch geometry, assembly mates define equivalent relations with respect to the individual parts or components, allowing the easy construction of assemblies. SolidWorks also includes additional advanced mating features such as gear and cam follower mates, which allow modeled gear assemblies to accurately reproduce the rotational movement of an actual gear train.

Finally, drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC).

INTRODUCTION OF FEA:

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures". By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters.FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design Modifications to meet the new condition. There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less.

ANSYS

Ansys Inc. is an American public company based in Canonsburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties.

Ansys was founded in 1970 by John Swanson. Swanson sold his interest in the company to venture capitalists in 1993. Ansys went public on NASDAQ in 1996. In the 2000s, Ansys made numerous acquisitions of other engineering design companies, acquiring additional technology for fluid dynamics, electronics design, and other physics analysis.

Ansys develops and markets finite element analysis software used to simulate engineering problems. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys software may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products. Typically Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyzes movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Ansys also develops software for data management and backup, academic research and teaching. Ansys software is sold on an annual subscription basis.

BEAM AXLE

A **beam axle** is a rigid beam which connects a nearside wheel and an offside wheel. This kind of hub is used mainly on larger vehicles, where a beam axle is fitted instead of independent suspension. This axle is also often found on trailers and in both the front and rear of four-wheel drive trucks.

Rear axle

- A **rear axle** is a rotating shaft at the rear of a vehicle to which engine power is transmitted through transmission rod for the drive.
- Vehicle design can be quite variable, and axles come in a range of formats and designs to meet different needs.
- Replacement of a front axle may be necessary in the wake of a serious accident or other damage, like heavy rusting.

CHAPTER 2

LITERATURE REVIEW

Moreno, Gonzalo, Vangelo Manenti, Gustavo Guerero, Lauro Nicolazzi, Rodrigo Vieira, and Daniel Martins. "Stability of Heavy Articulated Vehicles: Effect of Load Distribution." ***Transportation research procedia*** **33 (2018): 211-218.** In this paper, the influence of load distribution on the stability of heavy articulated vehicles is analyzed. To conduct this research, the Davies method is used to obtain the static of the mechanism that represent the last trailer of the vehicle. Using this method, the longitudinal, lateral and vertical displacements of the center of gravity ( ) are investigated, and a sensitivity analysis is made. Finally, a numerical case study is showed and the results of this study demonstrate that the load distribution has important role on the static rollover threshold ( ) calculation.

Sert, E. and Boyraz, P., 2017. Optimization of suspension system and sensitivity analysis for improvement of stability in a midsize heavy vehicle. ***Engineering science and technology, an international journal*****,** ***20*****(3), pp.997-1012.** This paper presents a method for systematic investigations on static and dynamic roll behavior and improvement to the stability dynamics based on increasing roll stiffness of the suspension. One of the major differences of this study from previous work is that it includes parametric sensitivity analysis in order to increase the safety margin from the roll angle threshold using the static and dynamic tests and it compares the results within themselves.

Russell, B., 2018. *Development and analysis of active rear axle steering for 8x8 combat vehicle* (Doctoral dissertation). This thesis proposes and compares multiple vehicle dynamics controllers using rear axle steering of an 8x8 combat vehicle. The controllers are assessed on ability to increase maneuverability at low speed, increase stability at higher speeds, avoiding rollover and ability to dampen the effects of external disturbances. The two controllers that are proposed to improve the lateral vehicle dynamics include a feed-forward Zero Side Slip (ZSS) controller which steers the rear axle based on the vehicle speed, and a Linear Quadratic Regulator (LQR) controller that monitors the steering angle and compares the vehicle yaw rate and sideslip angle to the desired values calculated at steady state.

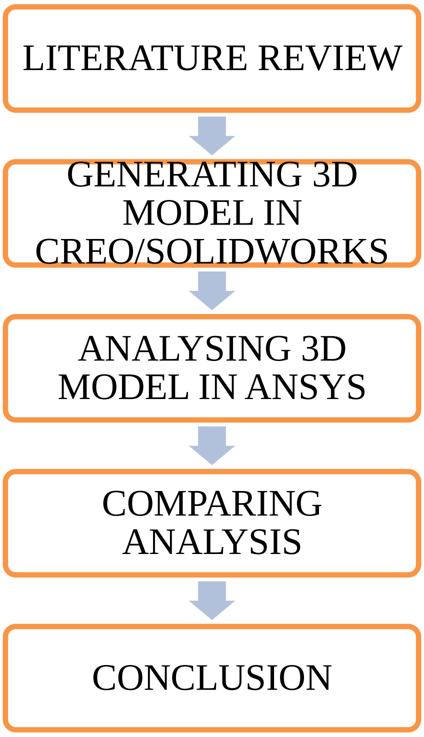
Kwasniewski, Leslaw, Hongyi Li, Jerry Wekezer, and Jerzy Malachowski. "Finite element analysis of vehicle–bridge interaction." *Finite Elements in Analysis and Design* 42, no. 11 (2006): 950-959. This paper presents results of the finite element (FE) analysis of dynamic interaction between a heavy truck and a selected highway bridge on US 90 in Florida. FE analysis of vehicle–bridge interaction was conducted using commercial program LS-DYNA and the super computer at the Florida State University. Development and implementation of a detailed FE truck model with 3D suspension systems, pneumatic and rotating wheels, appropriate contact algorithms, allowed for realistic representation of the actual vehicle dynamic loading.

Topac, M. M., H. Günal, and N. S. Kuralay. "Fatigue failure prediction of a rear axle housing prototype by using finite element analysis." *Engineering Failure Analysis* 16, no. 5 (2009): 1474-1482. A premature failure that occurs prior to the expected load cycles during the vertical fatigue tests of a rear axle housing prototype is studied. In these tests, crack mainly originated from the same region on test samples. To determine the reason of the failure, a detailed CAD model of the housing was developed. Mechanical properties of the housing material were determined via tensile tests. Using these data, stress and fatigue analyses were performed by finite element method. Fatigue crack initiation locations and minimum number of load cycles before failure initiation were determined.

Lu, Y., Yang, S., Li, S. and Chen, L., 2010. Numerical and experimental investigation on stochastic dynamic load of a heavy duty vehicle. *Applied Mathematical Modelling*, *34*(10), pp.2698-2710. Numerical simulation and field test are used to investigate tire dynamic load. Based on multi-body dynamics theory, a nonlinear virtual prototype model of heavy duty vehicle (DFL1250A9) is modeled. The geometric structural parameters of the vehicle system, the nonlinear characteristics of shock absorber and leaf springs are precisely described. The dynamic model is validated by testing the data, including vertical acceleration of driver seat, front wheel, intermediate wheel and rear wheel axle head.

CHAPTER 3

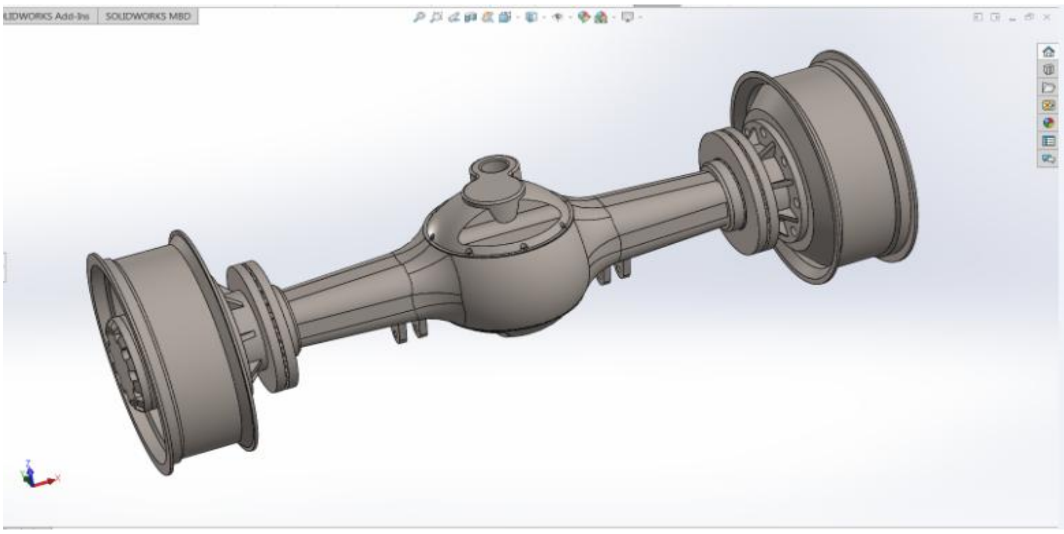
METHODOLOGY



First, the actual Heavy duty truck Rear axle is taken up from sources for analysis.

- Then it is analyzed through the ANSYS Workbench Software by applying vertical load of 30KN acting downwards on the axle beam.
- Similar loading conditions are tested for four different materials: Structural steel, Magnesium Alloy, Cast Iron and Titanium Alloy
- The analysis done for each of the four different materials are deformation, equivalent elastic strain and equivalent stress.
- Finally each type of analysis is compared for three materials and studied.

MODELING

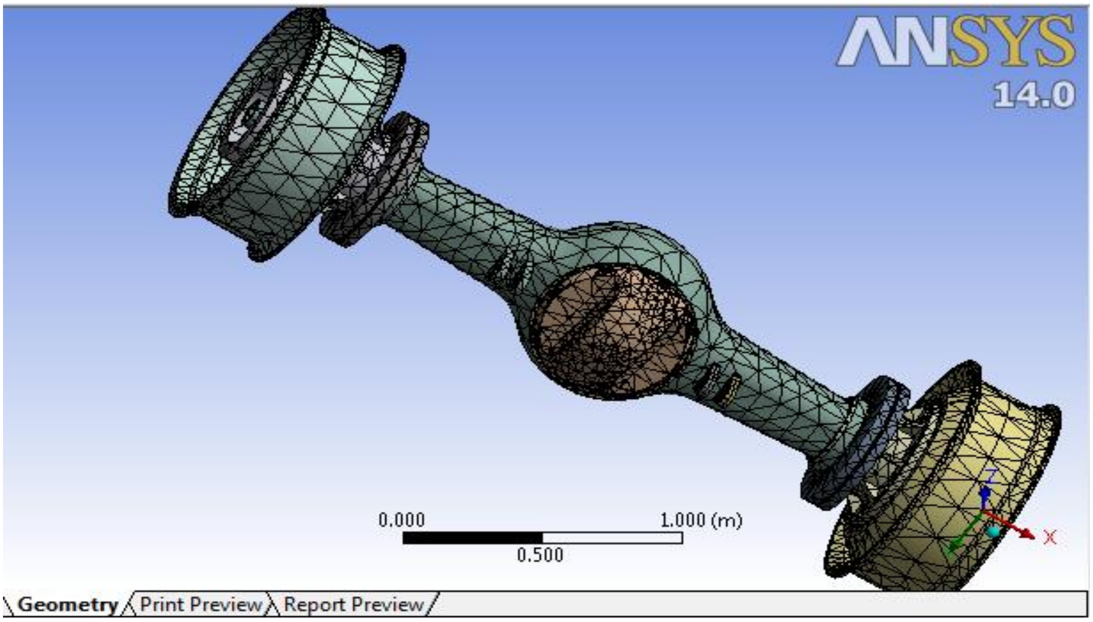


CHAPTER 4

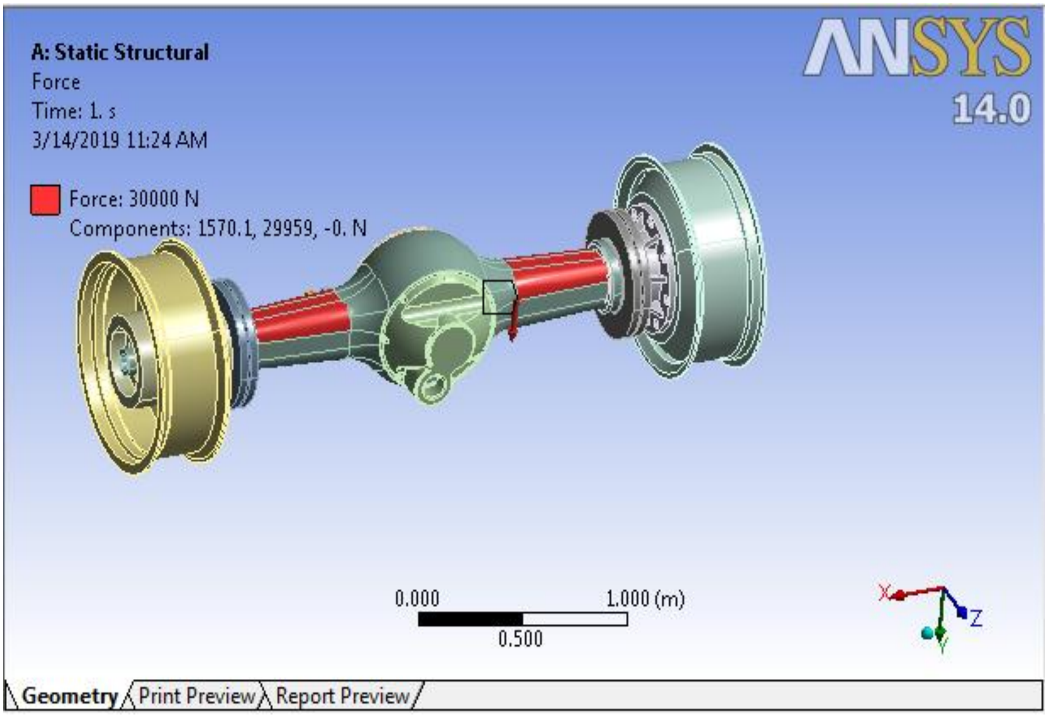
ANALYSIS

PRE-REQUISITES

MESHING



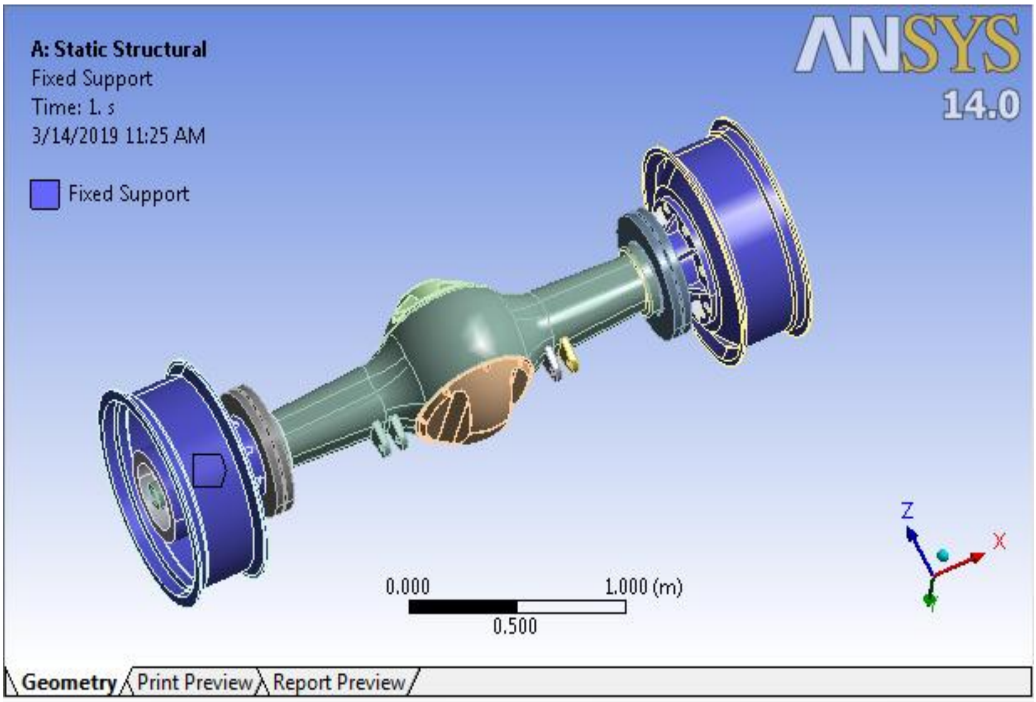
FORCE APPLICATION



A: Static Structural
Force
Time: 1. s
3/14/2019 11:24 AM

🟥 Force: 30000 N
Components: 1570.1, 29959, -0. N

FIXED SUPPORT



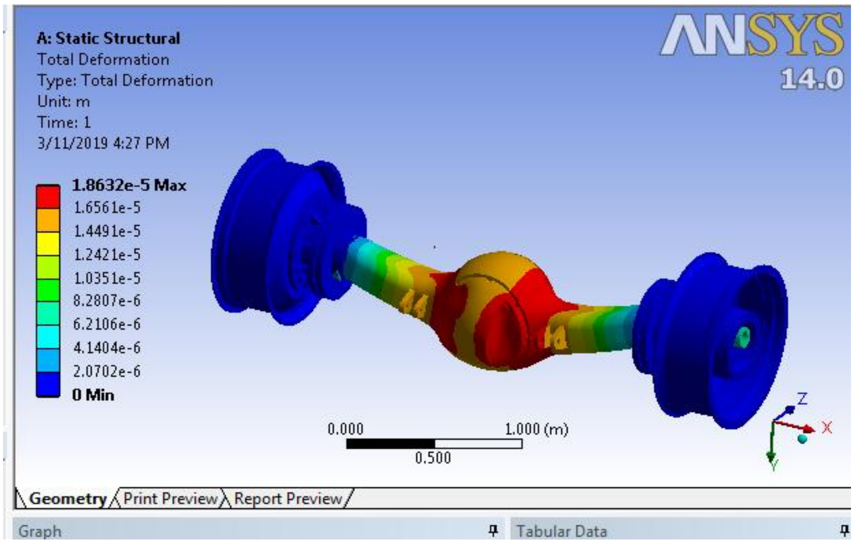
A: Static Structural
Fixed Support
Time: 1. s
3/14/2019 11:25 AM

🟦 Fixed Support

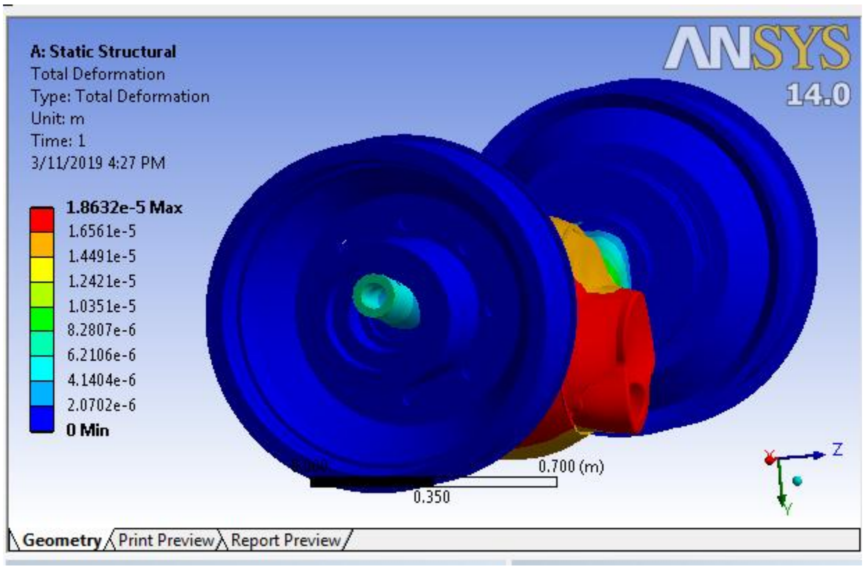
POST-ANALYSIS RESULTS

STRUCTURAL STEEL

DEFORMATION

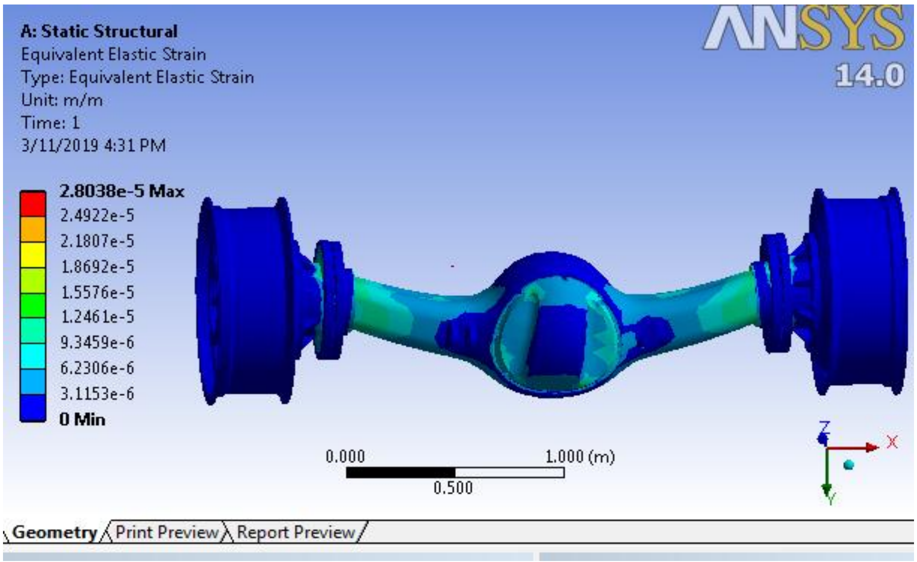


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 4:27 PM

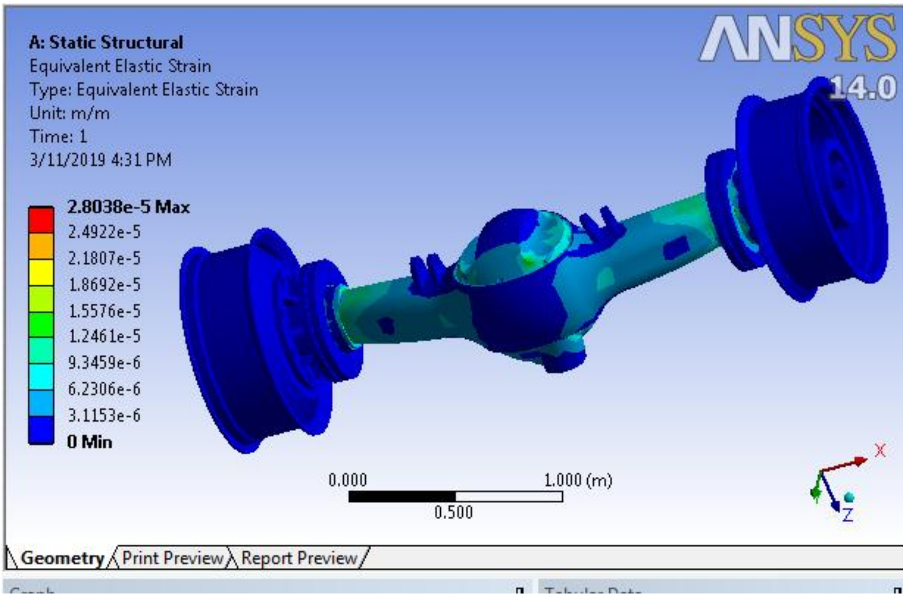


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 4:27 PM

EQUIVALENT ELASTIC STRAIN

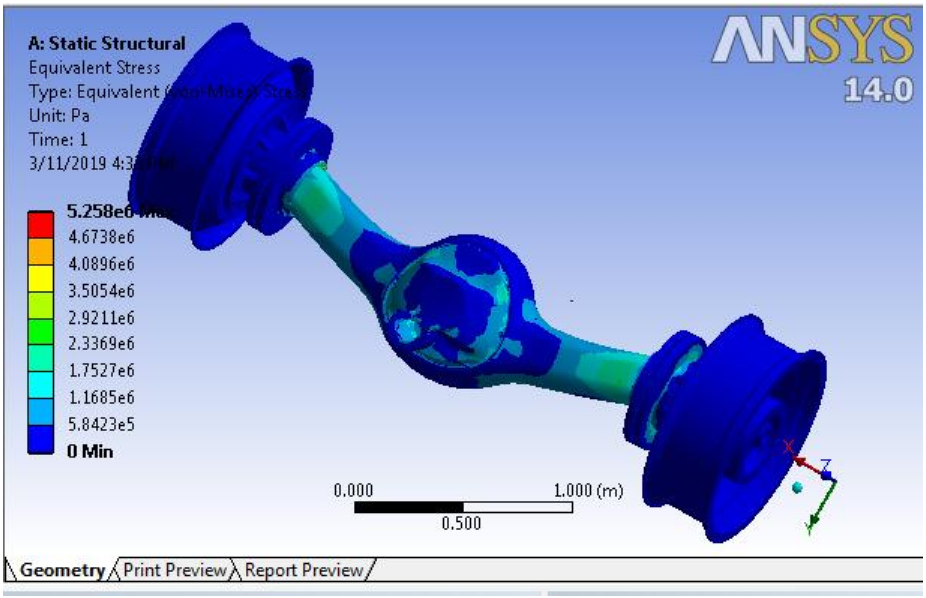


A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/11/2019 4:31 PM

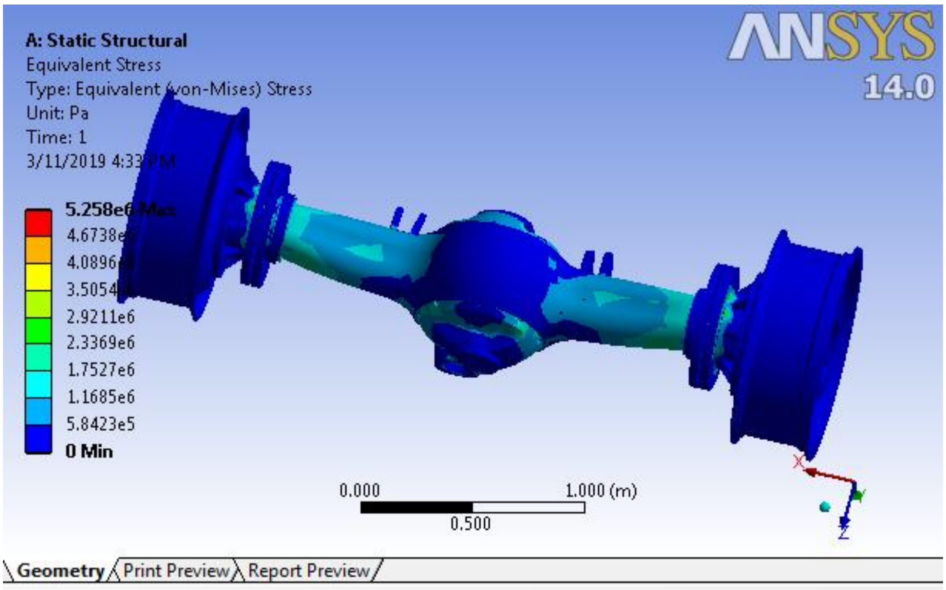


A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/11/2019 4:31 PM

EQUIVALENT STRESS



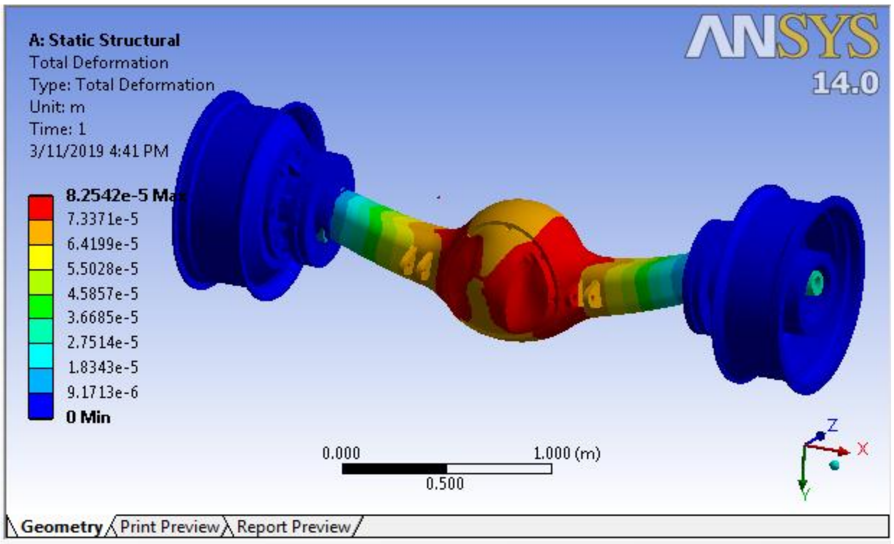
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/11/2019 4:3



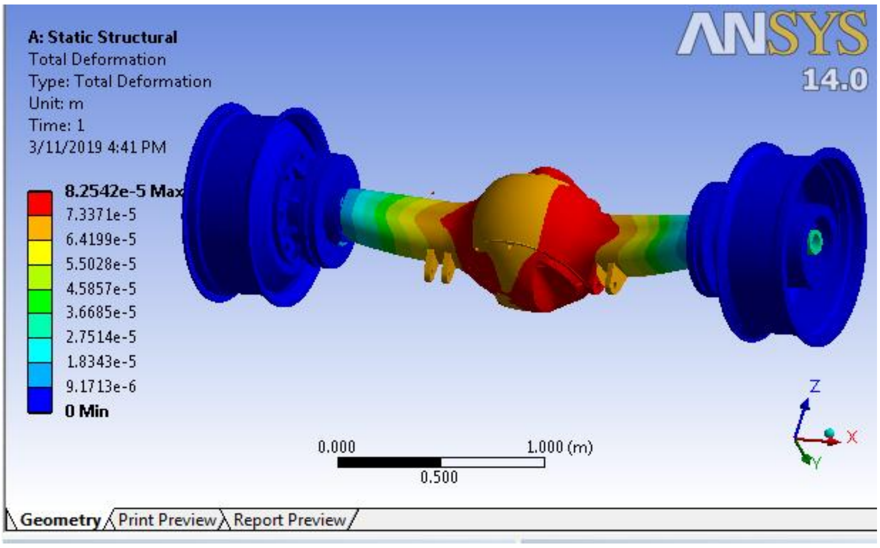
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/11/2019 4:33 PM

MAGNESIUM ALLOY

DEFORMATION

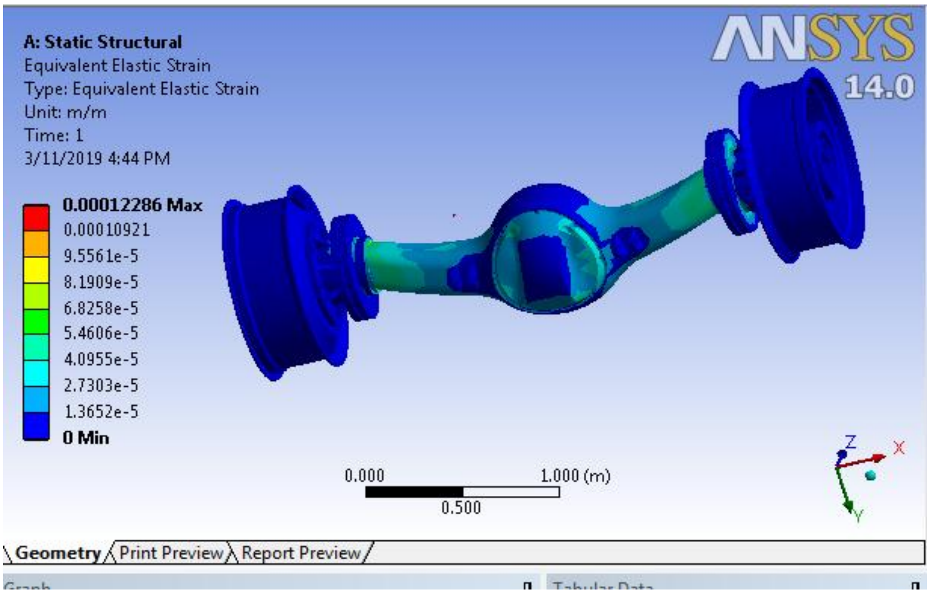


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 4:41 PM

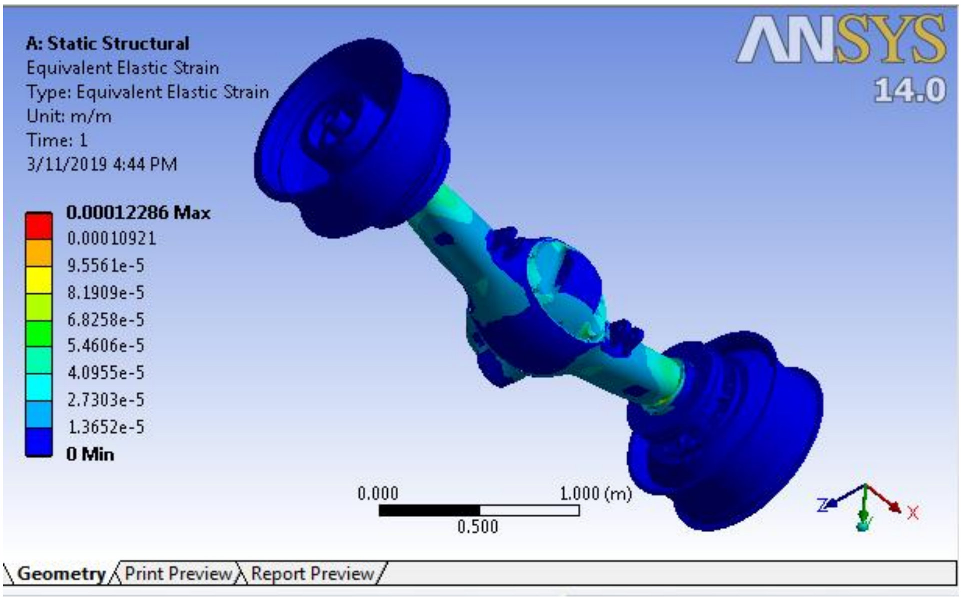


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 4:41 PM

EQUIVALENT ELASTIC STRAIN

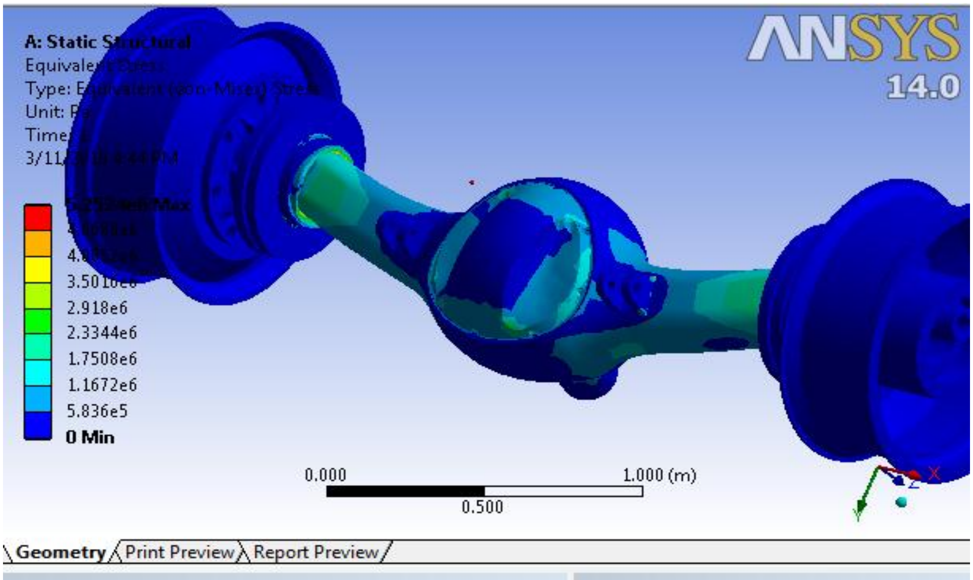


A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/11/2019 4:44 PM

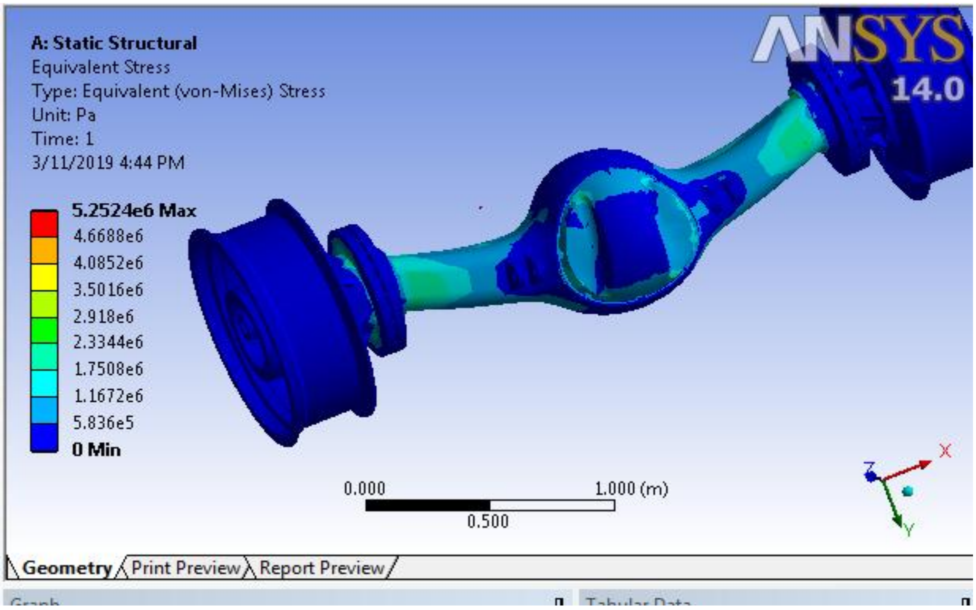


A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/11/2019 4:44 PM

EQUIVALENT STRESS



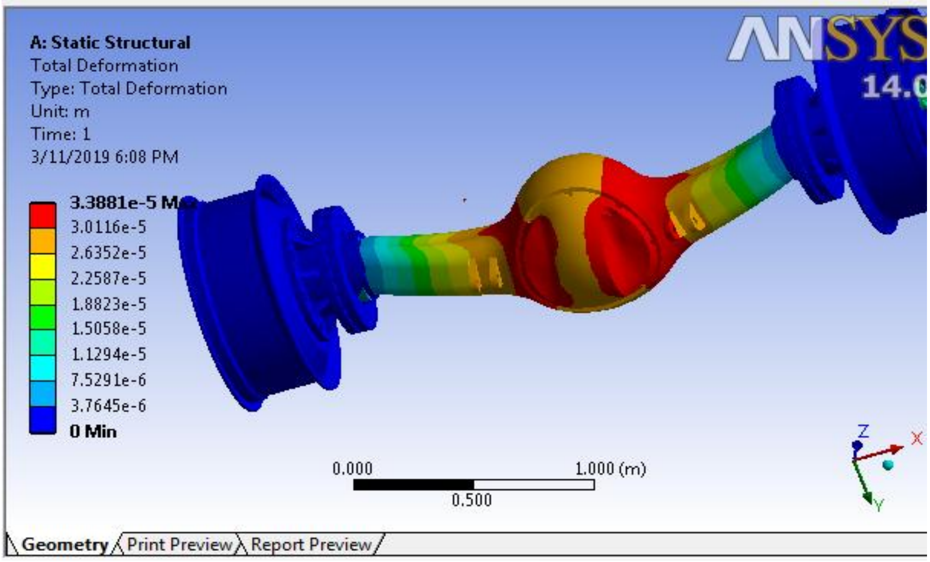
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: P
Time
3/11/



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/11/2019 4:44 PM

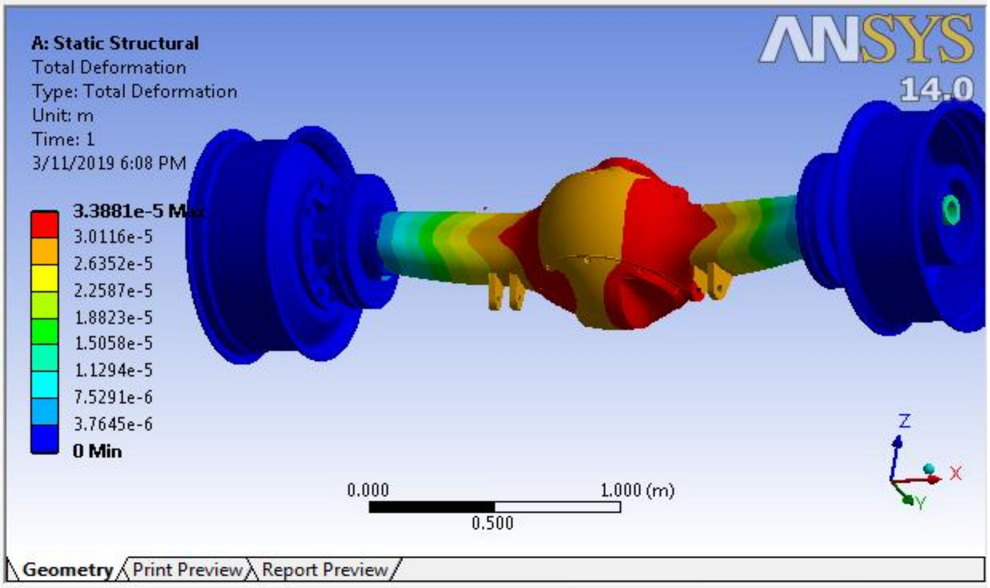
CAST IRON

DEFORMATION



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 6:08 PM

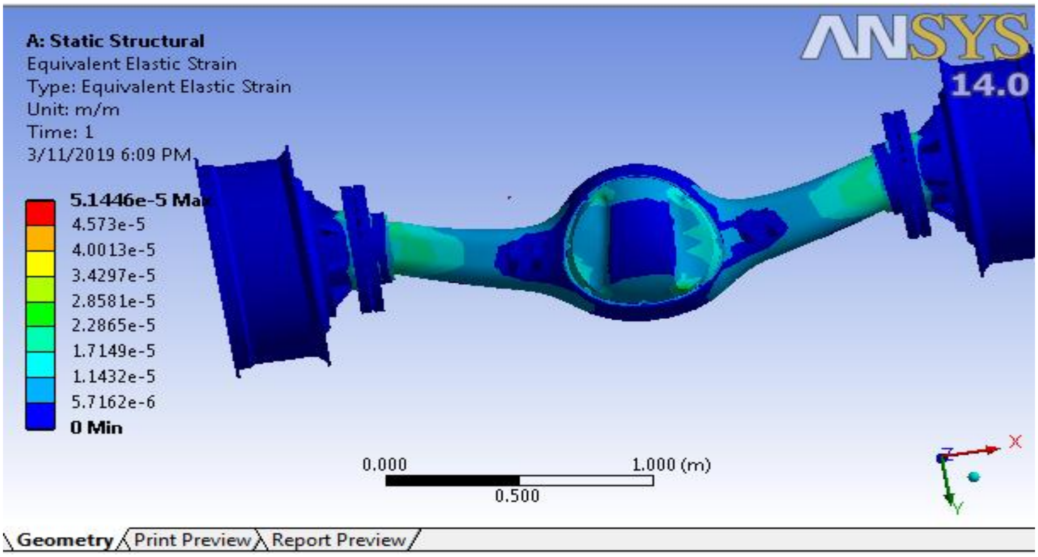
3.3881e-5 Ma
3.0116e-5
2.6352e-5
2.2587e-5
1.8823e-5
1.5058e-5
1.1294e-5
7.5291e-6
3.7645e-6
0 Min



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/11/2019 6:08 PM

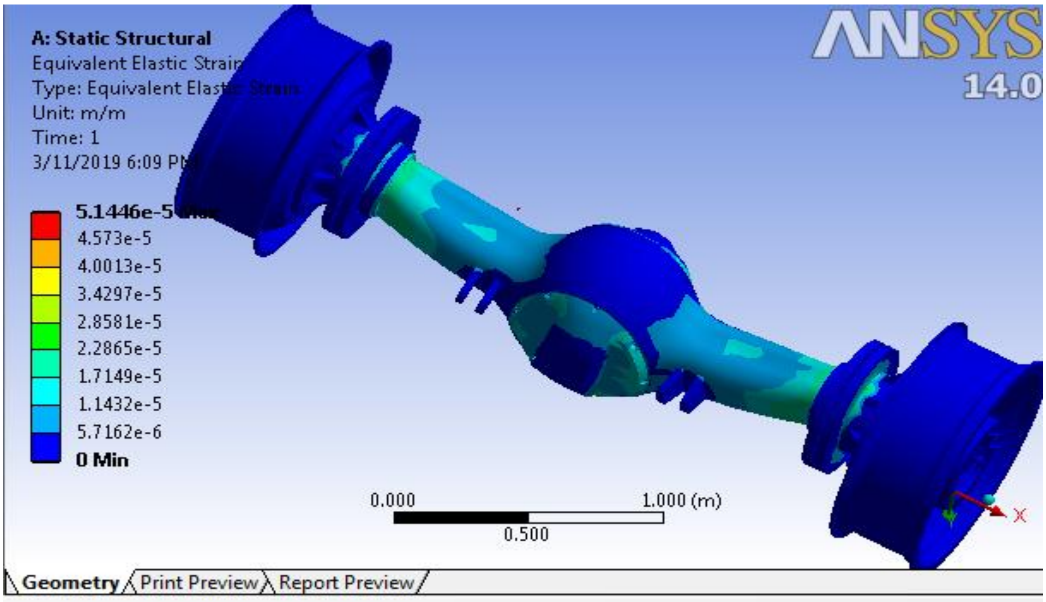
3.3881e-5 Ma
3.0116e-5
2.6352e-5
2.2587e-5
1.8823e-5
1.5058e-5
1.1294e-5
7.5291e-6
3.7645e-6
0 Min

EQUIVALENT ELASTIC STRAIN



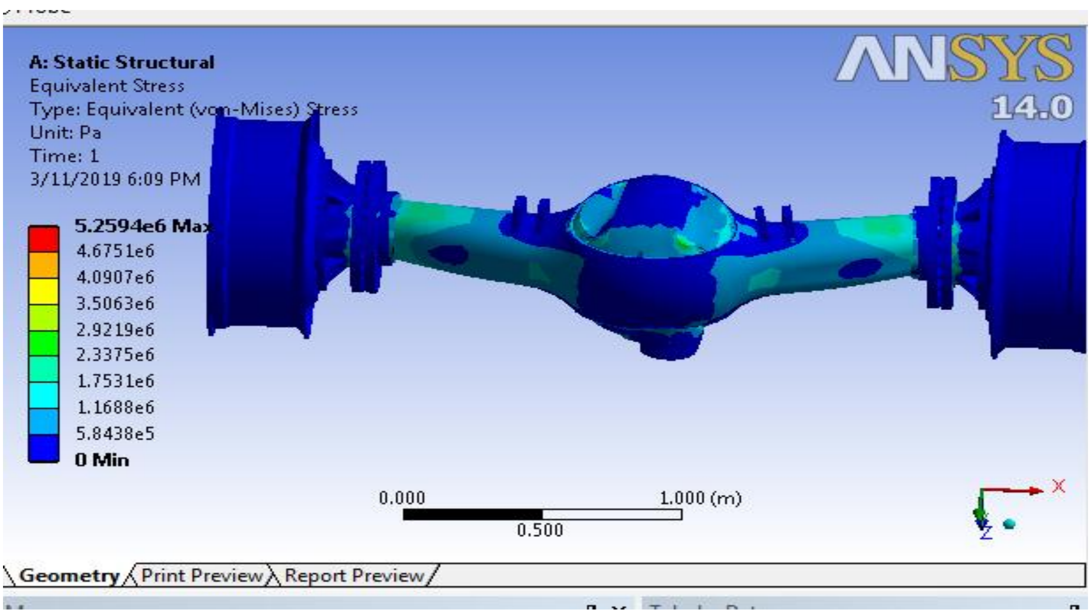
A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/11/2019 6:09 PM

5.1446e-5 Ma
4.573e-5
4.0013e-5
3.4297e-5
2.8581e-5
2.2865e-5
1.7149e-5
1.1432e-5
5.7162e-6
0 Min

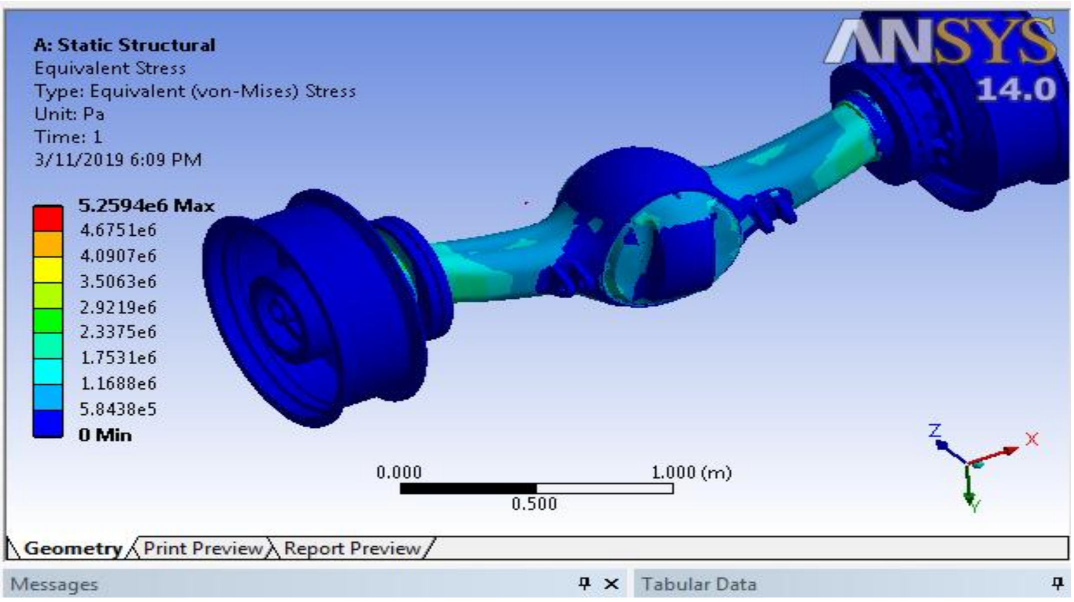


A: Static Structural
Equivalent Elastic Strai
Type: Equivalent Elas
Unit: m/m
Time: 1
3/11/2019 6:09 P

EQUIVALENT STRESS



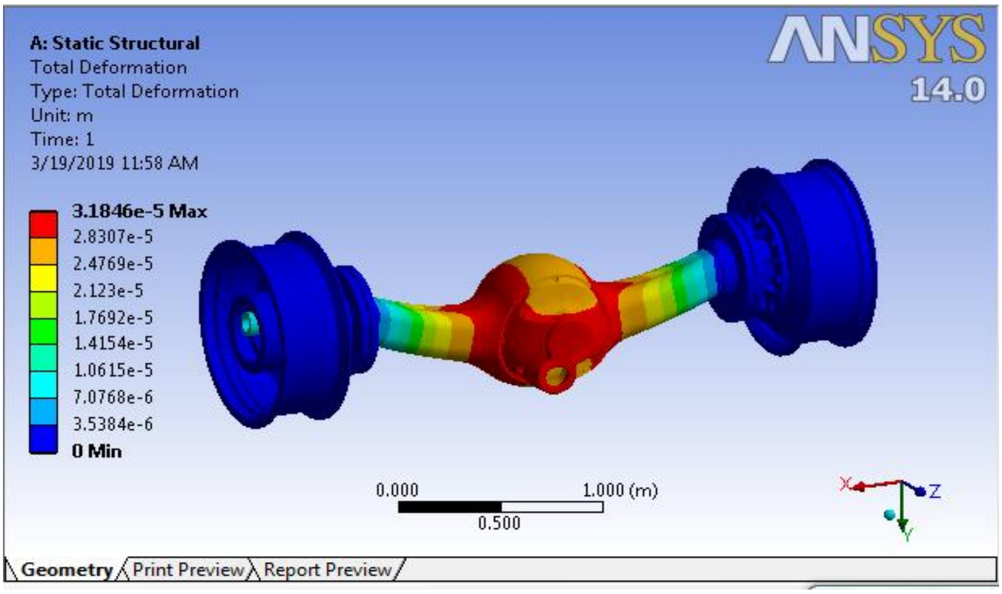
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/11/2019 6:09 PM



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/11/2019 6:09 PM

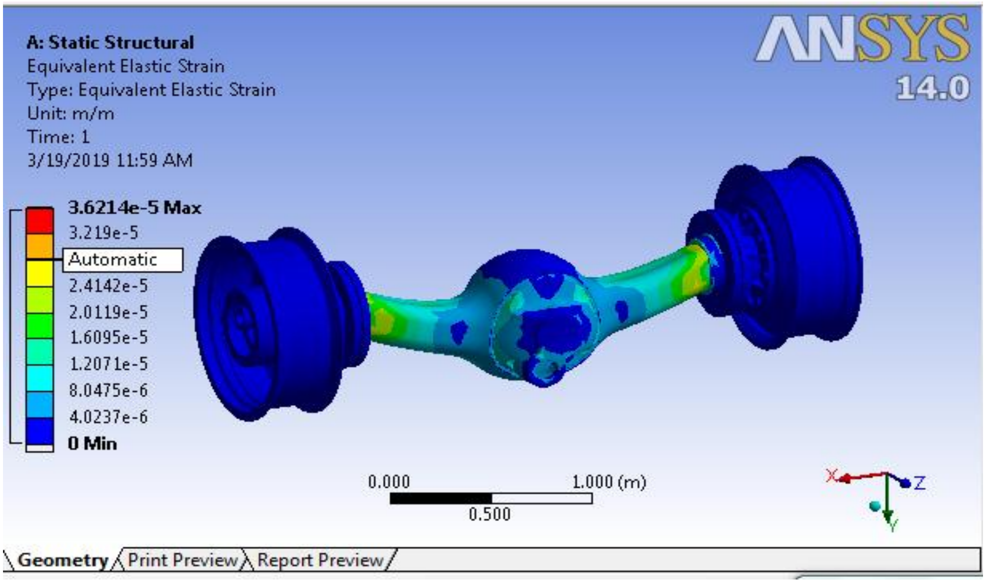
TITANIUM ALLOY

DEFORMATION



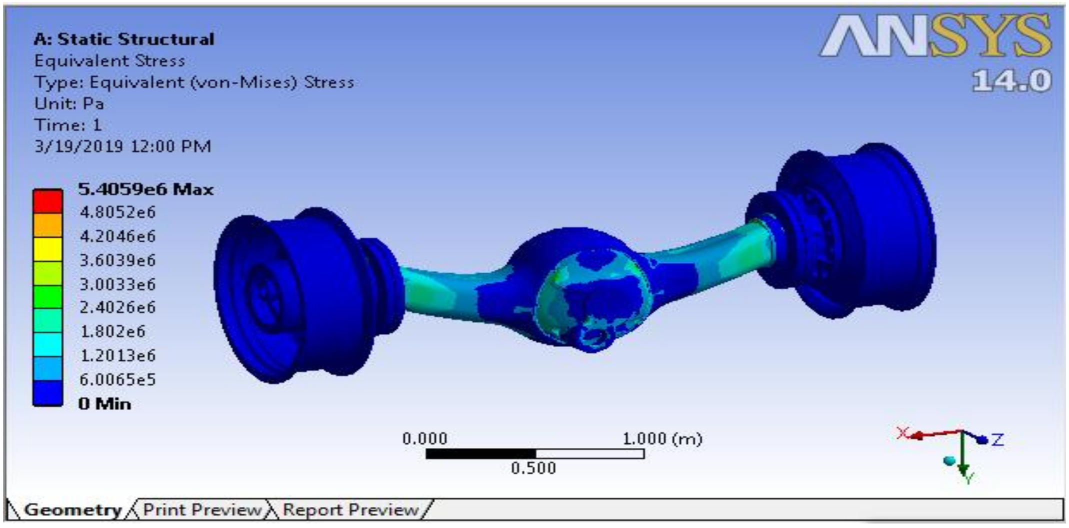
A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
3/19/2019 11:58 AM

EQUIVALENT ELASTIC STRAIN



A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
3/19/2019 11:59 AM

EQUIVALENT STRESS



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
3/19/2019 12:00 PM

CHAPTER 5

RESULT AND DISCUSSION

From the Static Structural Analysis the total deformation and von mises equivalent elastic strain and equivalent stress values for both the materials are tabulated

MODEL	LOAD (KN)	DEFORMATION (m)	EQUIVALENT ELASTIC STRAIN(m/m)	EQUIVALENT STRESS(Pa)
Structural Steel	30	1.8632E^-5	2.8038E-5	5.258E^6
Magnesium Alloy	30	8.2542E^-5	12.286E^-5	5.2524E^6
Cast Iron	30	3.3881E^-5	5.1446E^-5	5.259E^6
Titanium Alloy	30	3.185E^-5	3.621E^-5	5.406E^6

The Rear axle is modeled using the 3d Design software Cero Parametric/Solidworks. The model is then analyzed using the Analysis software. The static analysis is carried out in the Ansys software. The result of load are obtained from static analysis. The total deformation and von mises stress & strain are obtained from the static analysis. Different result sets for different materials are tabulated.

CONCLUSION

For a load of 30KN applied on the top surface area of the rear axle gave the results shown above, it is clear from it that the maximum deflection deformation has taken place in Magnesium Alloy with 8.2542E^-5m whereas the minimum was found to be in Structural Steel with 1.8632E^-5m. Similarly maximum Von Mises Equivalent Elastic strain is seen Magnesium Alloy with 12.286E^-5m and minimum of the same is Structural Steel with 2.8038E-5m. In the case of Von Mises Equivalent Stress the maximum and minimum values was seen in Titanium Alloy with 5.406E^6m and Cast Iron with 5.259E^6m respectively. Thus with the help of the analysis and results obtained for the particular load for the selected area with the chosen fixed support we can safely say the best material out of the four for withstanding heavy load. From the three materials taken into consideration the first priority is given to Structural Steel, followed by Titanium Alloy, Cast Iron and lastly Magnesium Alloy.

REFERENCE

[1] SiddarthDey, P.R.V.V.V Sri Rama ChandraMurthy. D, P.Baskar, "Structure analysis of front axlebeam of a light commercial vehicle," InternationalJournal of Engineering Trends and Technology ,Volume 11 Number 5 - may 2014.

[2] Ketan Vijay Dhande, PrashantUlhe, "Design andanalysis of front axle of heavy commercial vehicle,"International Journal of Science, Technology &Management, Volume No.03,Issue No.12, December2014.

[3] Aparajita P. Ray, Dr. R. R. Arakerimath, "DesignAnalysis and shape Optimization of front AxleofAutomotive Truck," International Journal ofEngineering and Management Research, PageNumber:54-58.

[4] Piyush C. Choudhari, Vimal D Sonara,Dr.PravinRathod, "Analysis and Design of TractorRear Axle Using Finite Element Method – A review,"International Journal of Advance Engineering andResearch Development Volume2, Issue 3, March –2015.

[5] Lalit Kumar, Chandrakant Singh, Bhumesh KumarDewangan, Prakash Kumar Sen, Shailendra KumarBohidar, "Study on the Front Axle and Rear AxleAttachment to Differential System," InternationalJournal for Innovative Research in Science &Technology, Volume 1, Issue 7, December 2014.

[6]JavadTarighi, SeyedSaeidMohtasebi, RezaAlimardani, "Static and Dynamic analysis of front axlehousing of tractor using finite element methods,"Australian Journal of Agricultural Engineering, AJAE2(2):45-49 (2011)

[7]KhairulAkmalShamsuddin,MohdSyamilTajuddin,MegatMohdAmzariMegatMohdAris,MohdNurhidayatZahelem, "Stress DistributionAnalysis of axle housing by using Finite ElementsAnalysis," The International Journal of Engineeringand Science, Volume 3, Issue 10, Pages 53-61, 2014.