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Optimized Propeller Shaft Design: Lightweight Material Selection Using FEA

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ABSTRACT

A shaft, also known as a driveshaft, driving shaft, tail shaft (in Australian English), propeller shaft (also known as a prop shaft), or Cardan shaft, is a device for transmitting mechanical power, torque, and rotation. It is typically used to connect other drivetrain parts that cannot be connected directly due to their location or the need to allow for relative movement between them. Drive shafts need to be protected and optimized for this reason in order to increase performance and decrease losses. The subject of the current study is which also optimizes the material used in drive shafts to reduce their weight without sacrificing the desired performanceof the shaft. Following the creation of the drive shaft model in Solidworks 2020, drive shafts were analyzed using ANSYS 19.2. Different materials, including Kevlar, epoxy carbon, epoxy e-glass, epoxy resin, carbon fibre, inconel 625, and inconel 718, are employed to conduct the analysis. Weight, Von-Mies Stress, Total Deformation, Equivalent Elastic Strain, Maximum Principal Stress, Shear Stress, and Equivalent Shear Strain have all been taken into consideration while comparing these materials. The findings of the study resulted that Inconel materials may be utilized to create drive shafts and with enhance performance shafts' functionality. In order of minimum weight and better performance the materials are given in order as Kevlar, epoxy carbon, epoxy e-glass, epoxy resin, carbon fibre, inconel 625, and inconel 718 respectively.

Keywords: Drive Shaft, ANSYS 19.2, Solidworks 2020, Kevlar, Epoxy Carbon, Epoxy E-Glass, Epoxy Resin, Carbon Fibre, Inconel 625, Inconel 718, Weight Reduction, Weight, Von-mises Stress, Total Deformation, Equivalent Elastic Strain, Maximum Principal Stress, Shear Stress & Equivalent Shear Strain

1. Introduction

Automobiles, commonly referred to as cars or motorcars, are typically four-wheeled vehicles primarily intended for the transportation of passengers. They are generally powered by internal combustion engines that utilize volatile fuels.

The contemporary automobile represents a sophisticated technical system that incorporates various subsystems, each designed for specific functions. Many of these subsystems comprise thousands of components that have developed through advancements in existing technologies or the introduction of new technologies, including electronic computing, high-strength plastics, and innovative alloys of steel and nonferrous metals. Additionally, the evolution of certain subsystems has been influenced by factors such as air quality regulations, safety standards, and competitive dynamics among global manufacturers.

Passenger vehicles have become the predominant mode of family transportation, with an estimated 1.4 billion vehicles in use globally. Approximately 25% of these are located in the United States, where over three trillion miles (nearly five trillion kilometers) are driven annually. In recent years, American consumers have had access to hundreds of different car models, with about half originating from international manufacturers. To leverage their unique technological innovations, manufacturers frequently launch new designs. With around 70 million new vehicles produced each year worldwide, manufacturers have successfully segmented the market into numerous small yet profitable niches.

Advancements in technology are widely acknowledged as essential for maintaining competitive advantage. All automobile manufacturers and suppliers have engaged research and development engineers and scientists to enhance various components, including the body, chassis, engine, drivetrain, control systems, safety features, and emission-control technologies.

The design of a vehicle is significantly influenced by its intended application. Vehicles designed for off-road conditions must be robust, featuring straightforward systems that can withstand substantial overloads and extreme operating environments. In contrast, vehicles meant for high-speed, limited-access roadways necessitate greater passenger comfort, enhanced engine performance, and improved handling and stability at high speeds.

Stability is primarily determined by the weight distribution between the front and rear wheels, the height and position of the center of gravity in relation to the vehicle's aerodynamic center of pressure, suspension characteristics, and the choice of wheels used for propulsion. Weight distribution is largely influenced by the engine's placement and size. The prevalent practice of front-mounted engines takes advantage of the stability that this configuration offers. However, advancements in aluminum engine technology and innovative manufacturing techniques have enabled the placement of engines at the rear without significantly compromising stability.

2. Composite materials

Composite material (additionally known as a composition fabric or shortened to composite that is the commonplace name) is a material made from two or more constituent substances with considerably considered one of a kind physical or chemical residence that, even as mixed, produce a material with characteristics precise from the individual components. The character components remain separate and wonderful in the finished form, differentiating composites from combinations and strong solutions. The new fabric may be favoured for plenty motives. Common examples encompass substances which is probably stronger, lighter, or much less expensive while in comparison to traditional materials.

More currently, researchers have additionally all commenced to actively encompass sensing, actuation, computation and communication into composites, which might be referred to as Robotic Materials. Typical engineered composite substances consist of:

- Reinforced concrete and masonry
- Composite timber inclusive of plywood
- Reinforced plastics, including fibre-reinforced polymer or fiberglass
- Ceramic matrix composites (composite ceramic and metallic matrices)
- Metal matrix composites
- Other Advanced composite substances

Composite substances are usually used for buildings, bridges, and systems which includes boat hulls, swimming pool panels, racing automobile bodies, shower stalls, bathtubs, garage tanks, imitation granite and cultured marble sinks and counter tops.

The most superior examples carry out robotically on spacecraft and plane in traumatic environments.

Concrete is the maximum common synthetic composite fabric of all and typically consists of loose stones (combination) held with a matrix of cement. Concrete is a less expensive material, and will not compress or shatter even under quite a large compressive strain. However, concrete cannot continue to exist tensile loading (i.e., if stretched it will rapid damage aside). Therefore, to provide concrete the functionality to stand as much as being stretched, steel bars, that can face up to immoderate stretching forces, are often introduced to concrete to shape reinforced concrete.

Fibre-reinforced polymers (FRP) include carbon-fibre-bolstered polymer (CFRP) and glass-reinforced plastic (GRP). If categorized with the aid of matrix then there are thermoplastic composites, brief fibre thermoplastics, long fibre thermoplastics or lengthy fibre-strengthened thermoplastics. There are several thermoset composites, together with paper composite panels. Many advanced thermoset polymer matrix systems commonly include aramid fibre and carbon fibre in an epoxy resin matrix.

3. Problem Statement

For current research focuses on analysing the driveshaft of an *H-Series Ashok Leyland Engine, Truck model -6DT120.* Various dimensions of the drive shaft have been taken from previous research of S. Mohan et al. (2016)

(Source- https://www.idosi.org/mejsr/mejsr24(RIETMA)16/18.pdf).

Various dimensions of the drive shaft used by S. Mohan et al. (2016) is as follows-

S. No.	Description	Notations	Value (mm)
01	Outer Diameter	D	70
02	Inner Diameter	d	56
03	Thickness of the Shaft	t	7
04	Length of the Shaft	L	1800
05	Radius of the Shaft	r	31.5

Various materials have been employed in the current research study which are Kevlar, Epoxy Carbon, Epoxy E-Glass, Epoxy Resin, Carbon Fibre, Inconel 625, Inconel 718. All the materials ere compared with each other on the basis of different process parameters like Weight, Total Deformation, Equivalent Stress, Maximum principal stress.

4. Analysis of Drive Shaft

Drive Shaft is analyzed through static structural analysis on ANSYS software which is the mostly used software in CAE (Computer Aided Engineering) field. After creating solid model of Drive Shaft in Solidworks-2020, proceed as follows-

- Start the analysis process of the model in ANSYS Workbench through selecting the module of static structural analysis.
- Select the Drive shaft material according to the requirement. Insert the material properties as follows-

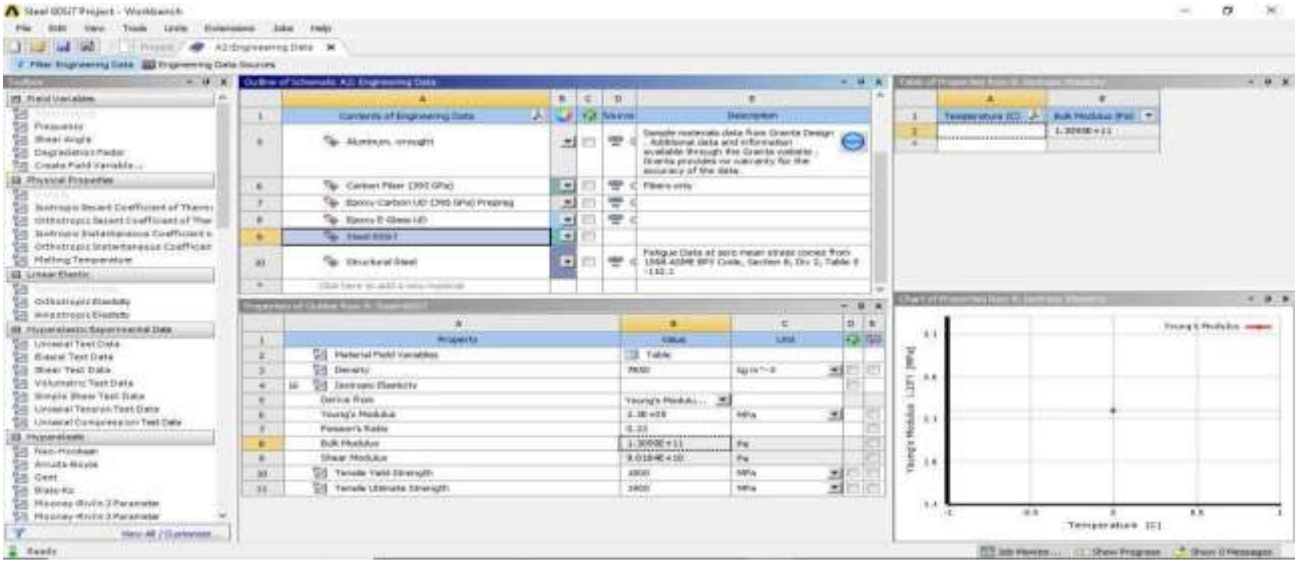


Fig. 4.1 Applying material to the current analysis

➢ Assign the materials Structural Steel for analyzing the CAD model.

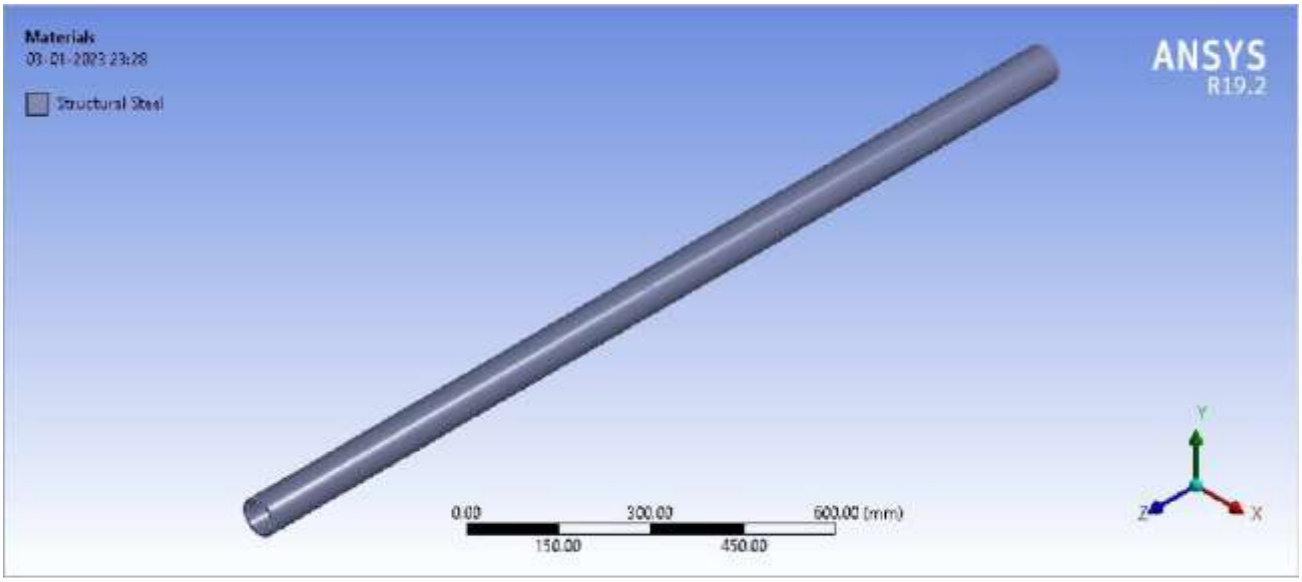


Fig. 4.2- Assigning the material into the model

➢ Meshing the component using default settings. In order to get the better results mesh size was refined to 4 mm.

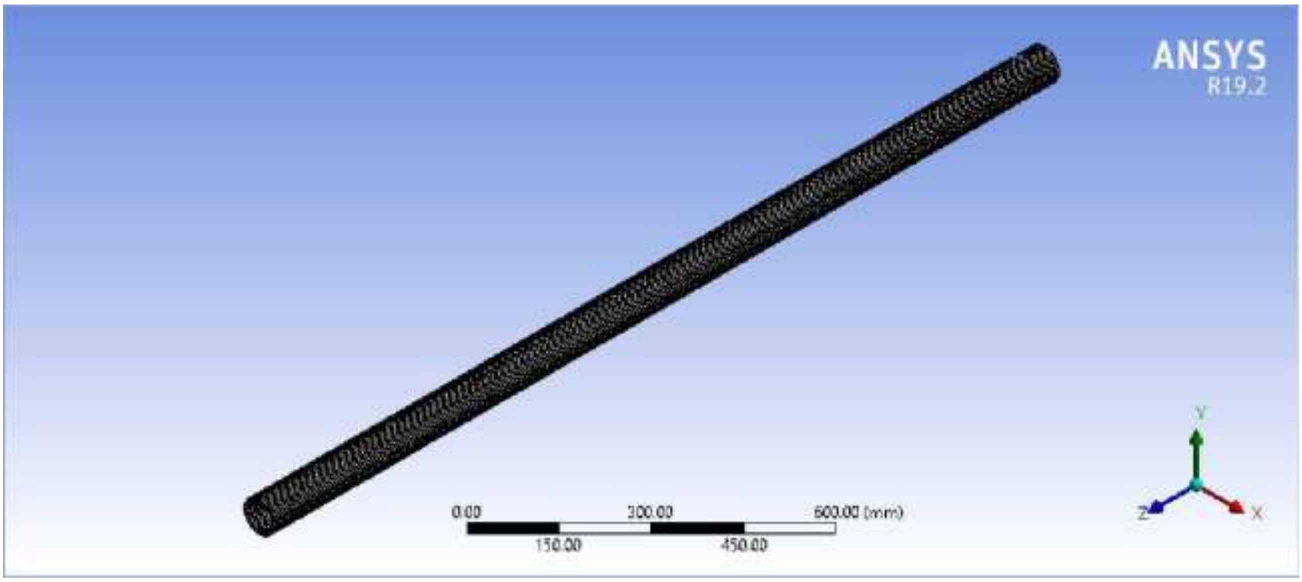
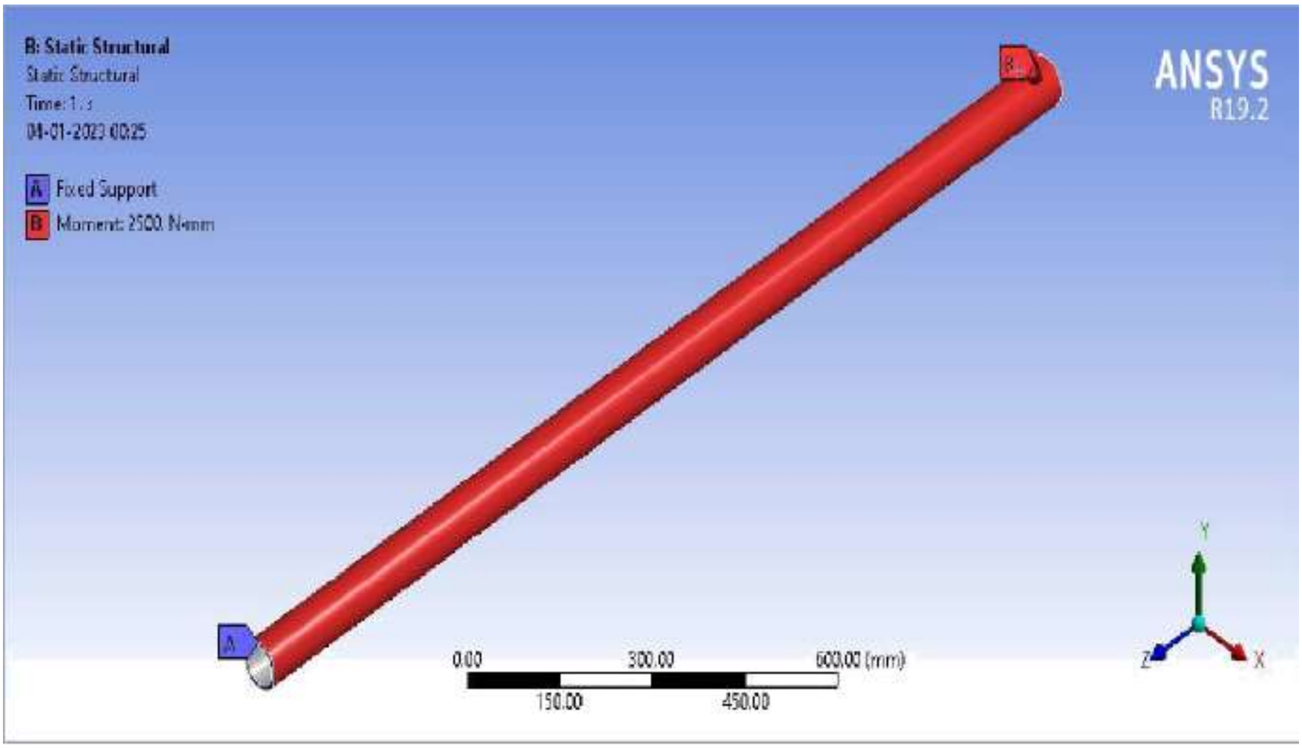


Fig. 4.3 -Meshing of the Drive Shaft

➢ Next step in the analysis is to apply the boundary conditions. One cross-sectional face was applied with fixed support. Other cross-sectional face and longitudinal face of the shaft were applied with a torque of 2500 N-mm.

➢ Solving the analysis for various results which include equivalent stress, maximum principal stress, shear stress, total deformation etc.

➢ Accessing the report for this particular analysis and interpreting the results.


B: Static Structural
Static Structural
Time: 1. s
04-01-2023 00:25

A Fixed Support
B Moment: 2500. N·mm

Fig. 4.4- Boundary Conditions being applied on the assembly

- Run the analysis
- Get the results.

Result Analysis of Drive Shaft

This particular case saw analyzing Drive Shaft for different mechanical properties of Structural steel. All the data is being presented here for reference.

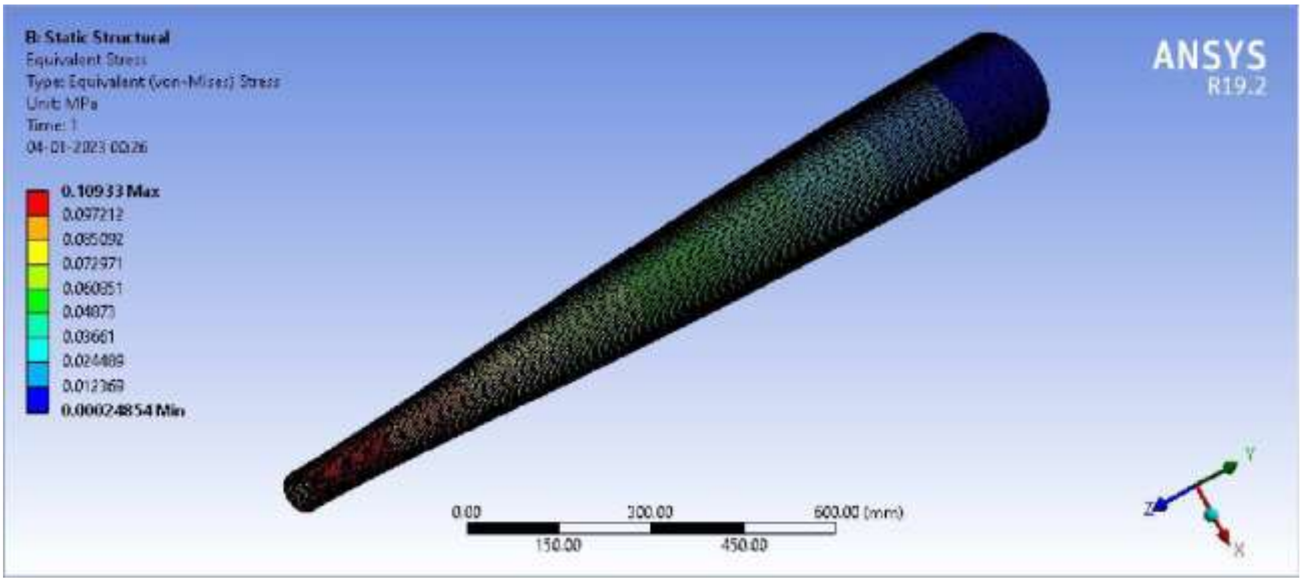


Fig. 4.5- Equivalent Stress Analysis of Structural Steel Drive Shaft

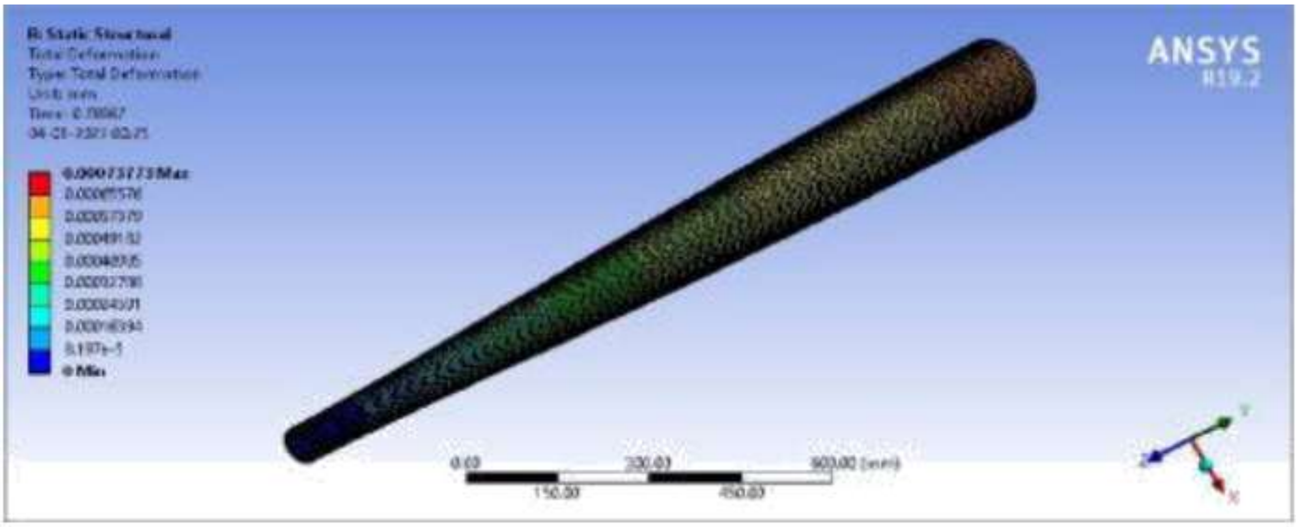


Fig. 4.6- Total Deformation of Structural Steel Drive Shaft

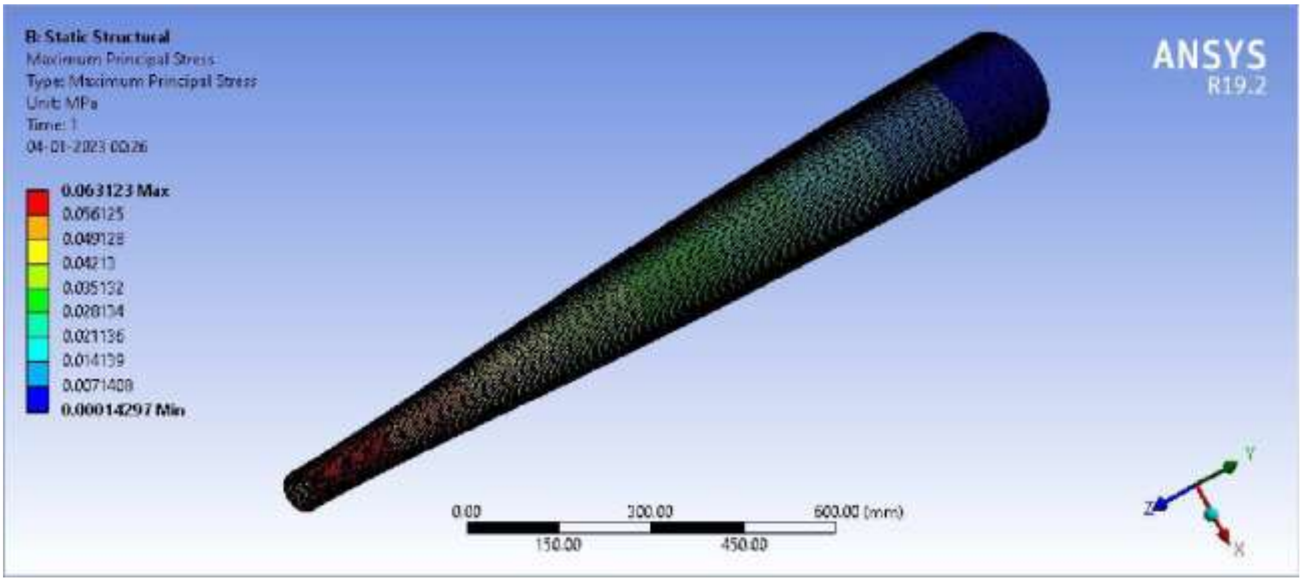


Fig. 4.7- Maximum Principal Stress distribution of Structural Steel Drive Shaft

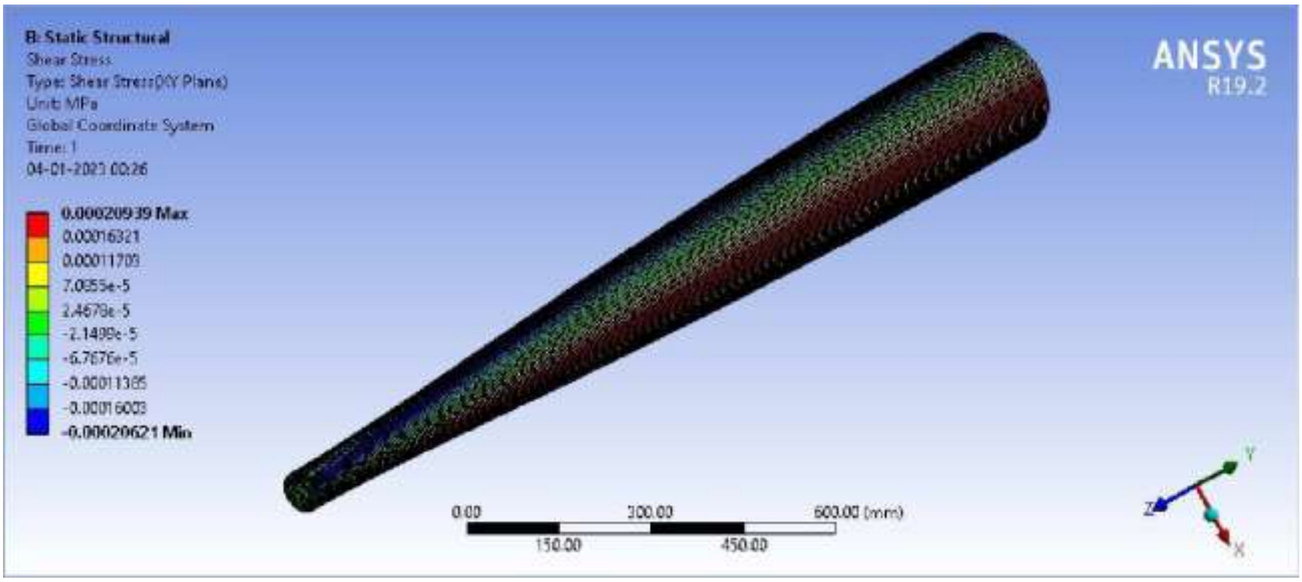


Fig. 4.8- Shear Stress Distribution of Structural Steel Drive Shaft

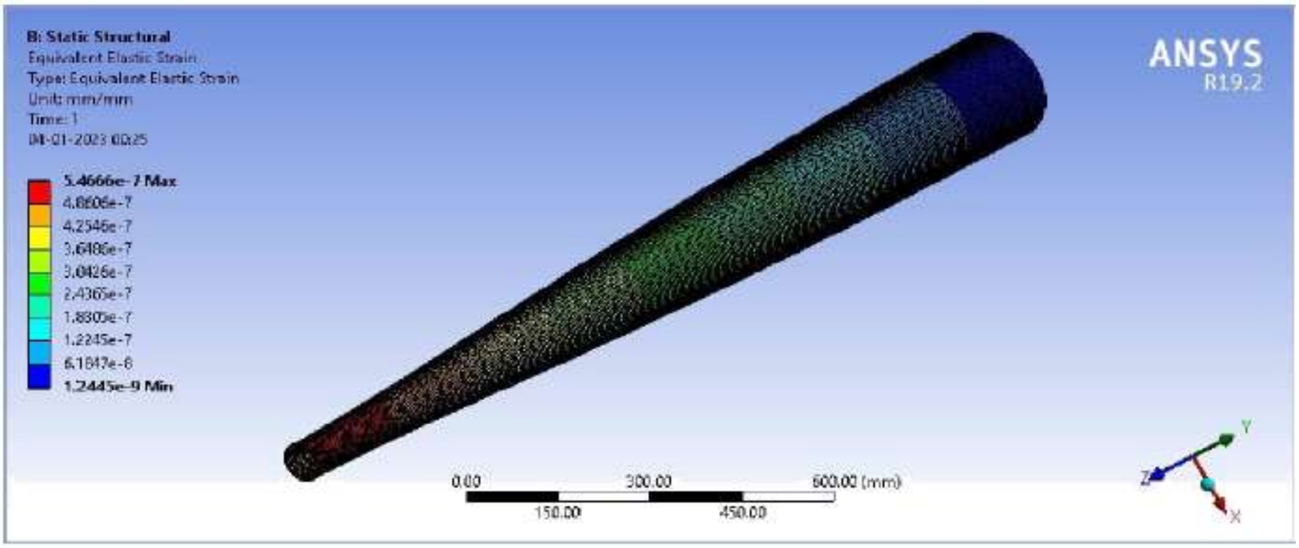


Fig. 4.9- Equivalent Elastic Strain Distribution of Structural Steel Drive Shaft

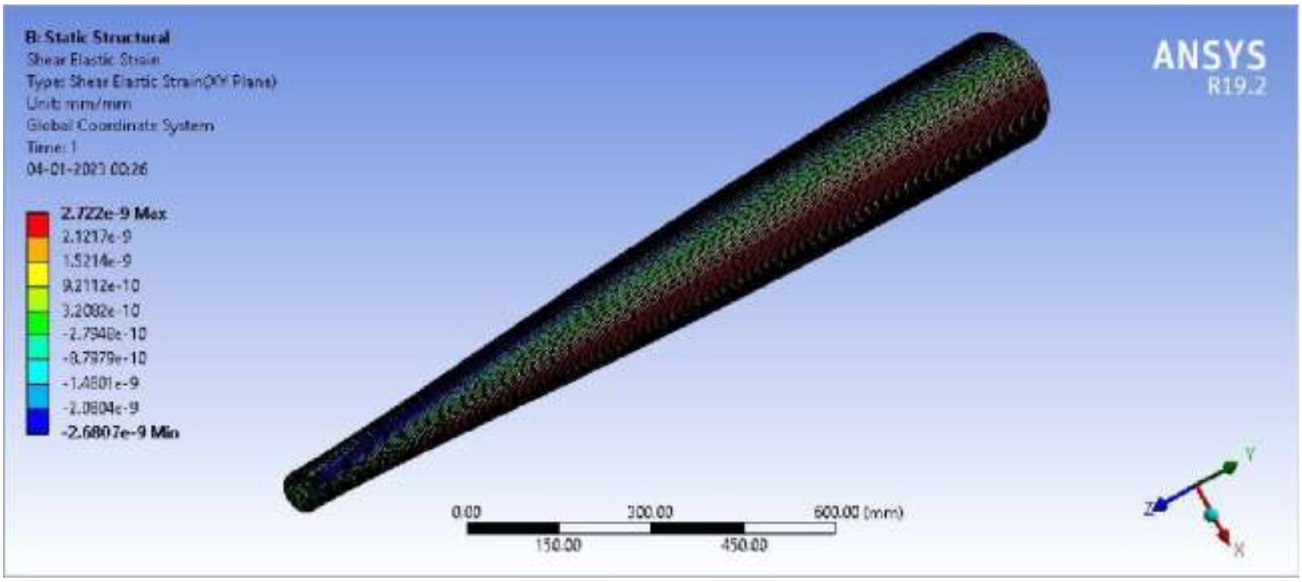


Fig. 4.10- Shear Elastic Strain Distribution of Structural Steel Drive Shaft Various

Once the analysis for all the materials is completed, next step would be to compare the results so that the material optimization is performed for the Drive Shaft. The results for all the process parameters of all materials are presented in form of a table as presented here for the reference-

S. No.	Material	Weight in Kg	Equivalent Stress in MPa	Total Deformation in mm	Maximum Principal Stress in MPa	Shear Stress in MPa	Equivalent Elastic Strain	Shear Elastic Strain
1	Structural Steel	19.57	0.11	0.0007	0.063	0.0002	0.0000005	0.000000003
2	Aluminium Alloy	6.91	0.109	0.0021	0.063	0.0002	0.000001	0.000000008
3	Asbestos	3.99	0.11	0.83	0.063	0.0002	0.0007	0.000003
4	Carbon Fibre	4.48	0.11	0.0066	0.066	0.0009	0.000006	0.0000001
5	Inconel 625	21.048	0.109	0.0009	0.063	0.0002	0.0000007	0.000000003
6	Inconel 718	20.497	0.109	0.0009	0.063	0.0002	0.0000007	0.000000003
7	Epoxy Carbon	3.72	0.12	0.015	0.079	0.0043	0.000016	0.00000093
8	Epoxy E Glass	4.98	0.116	0.013	0.073	0.0026	0.000013	0.00000053
9	Cork	0.488	0.109	4.43	0.063	0.0002	0.0034	0.00002
10	Kevlar	3.59	0.11	2.62	0.063	0.0002	0.0019	0.00001

Table. 01 Various Results of the Analysis

5. Data Interpretation

A. Weight pattern

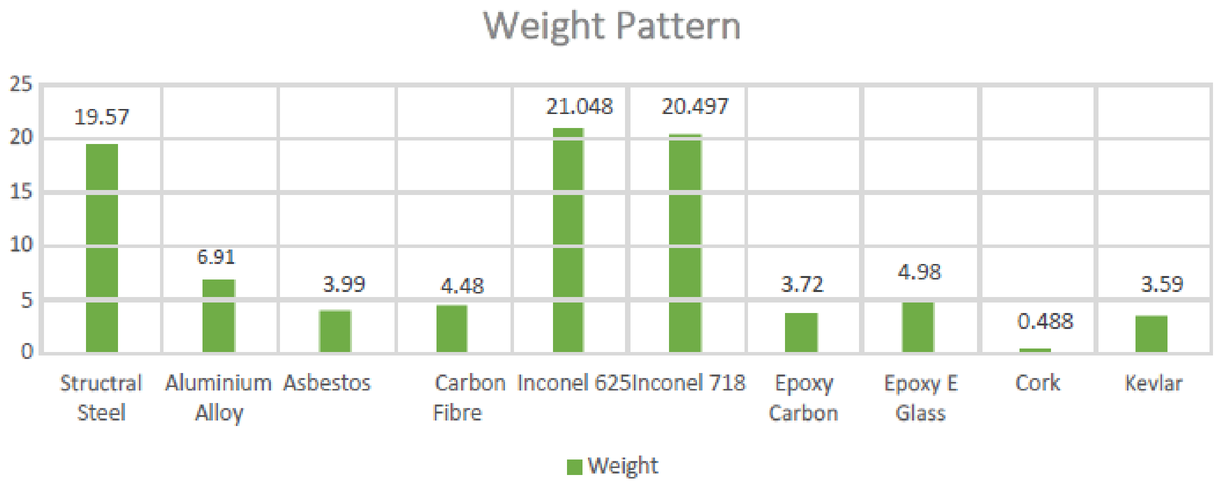


Fig. 5.1- Weight pattern

The plot of weight for all the materials have been plotted in above figure. Here one can clearly see that for structural steel, the weight of Drive Shaft is 19.57 kg which significantly reduces for aluminium alloy and comes down to 6.91 kg. It suddenly rises to 21.048 kg in case of Inconel 625. After that for all other materials it reduces and comes down to below 5 Kg. Hence this weight comparison plot shows that Aluminium alloy and all other composite materials along with ceramics are better suitable for Drive Shaft according to weight criteria.

B. Equivalent (Von-mises) Stress Pattern

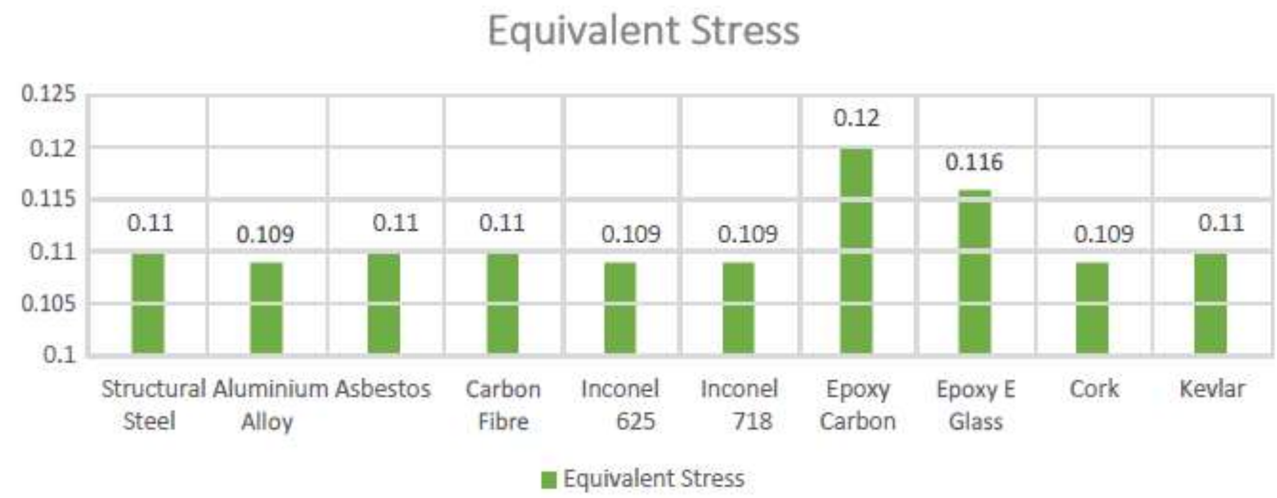


Fig. 5.2-Equivalent Stress Pattern

The plot of equivalent stress for all the materials have been plotted in above figure. Here one can clearly see that for Structural steel, the equivalent stress of Drive Shaft is 0.11 MPa which remains nearly equal for aluminium alloy, Asbestos etc. For Carbon Fibre & Epoxy materials, equivalent stress is approximately equal to Structural Steel. For Inconel materials too equivalent stress is nearly equal to conventional materials. Hence this equivalent stress comparison plot shows that all the materials are suitable for Drive Shaft according to this criterion.

C. Total Deformation Pattern

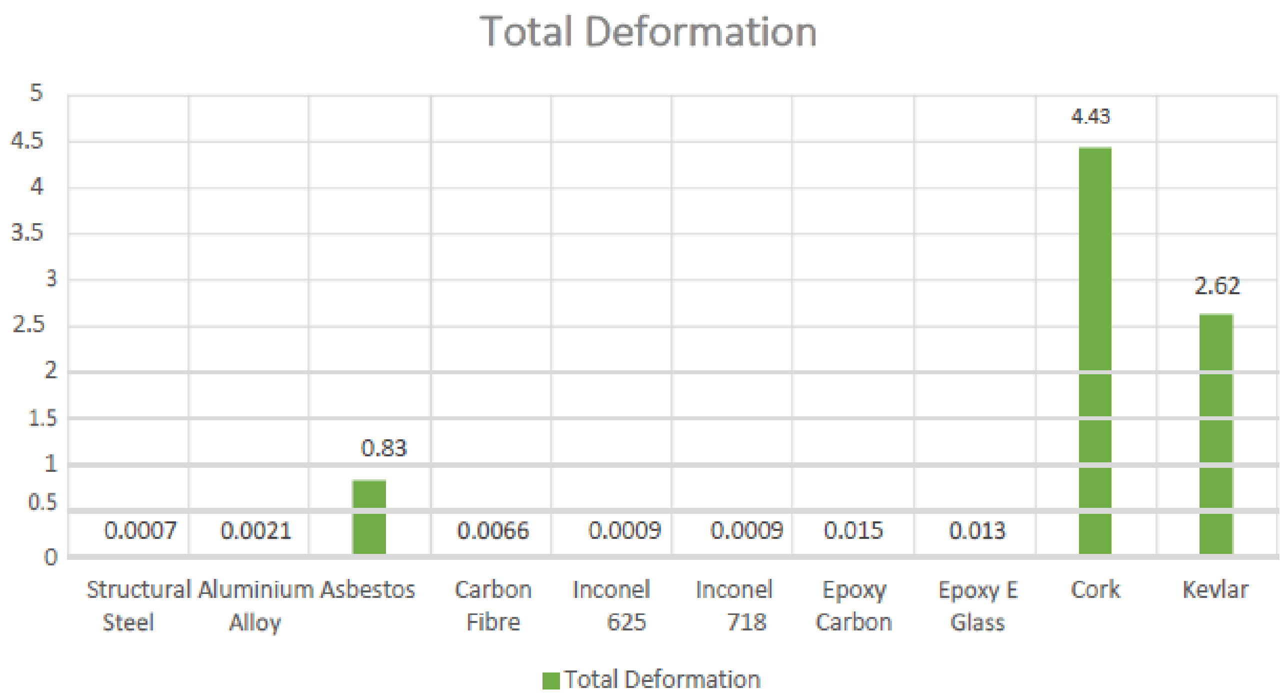


Fig. 5.3- Total Deformation Pattern

The plot of total deformation for all the materials have been plotted in above figure. Here one can clearly see that for structural steel, the total deformation of Drive Shaft is 0.0007 mm which increases for Aluminium Alloy, Asbestos & all other materials. This increment is not much in case of Inconel materials. Hence this total deformation comparison plot shows that conventional materials are better suitable for Drive Shaft. Although all other materials except ceramics can also be used for the application (since the values are less than even a single mm).

D. Maximum Principal Stress Pattern

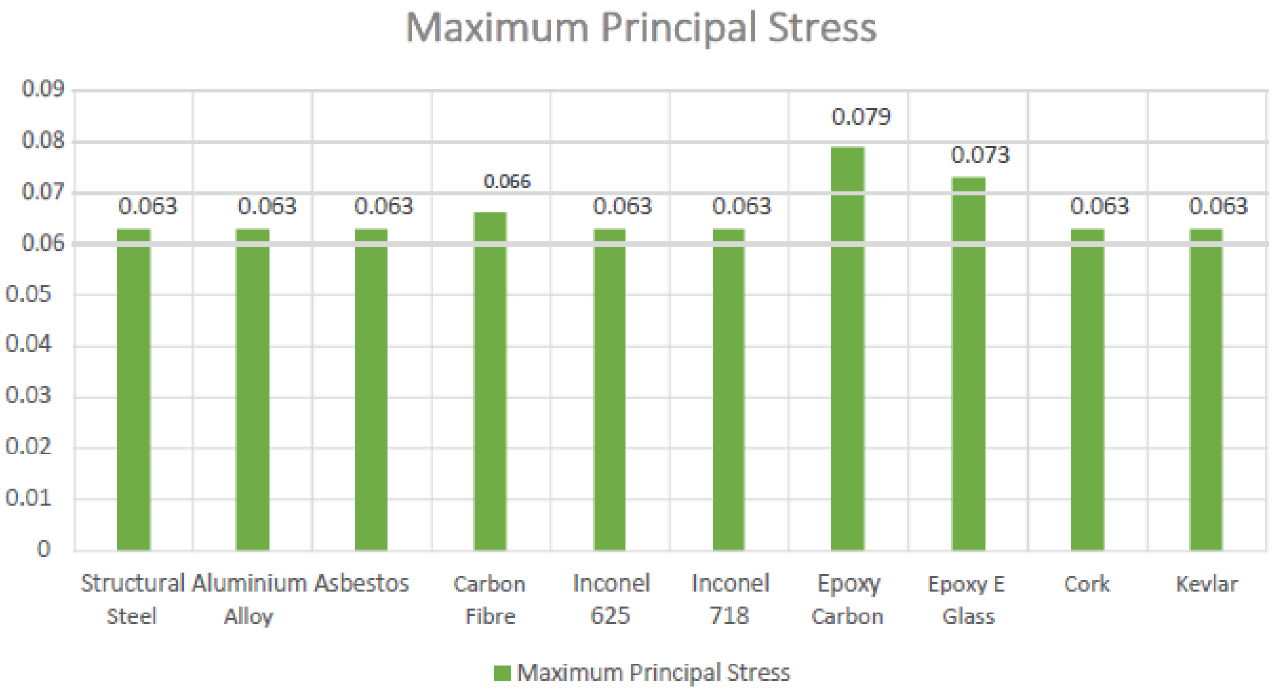


Fig. 5.4- Maximum Principal Stress Pattern

The plot of maximum principal stress for all the materials have been plotted in above figure. Here one can clearly see that for Structural steel, the maximum principal stress in case of Drive Shaft is 0.063 MPa which remains nearly equal for aluminium alloy, Asbestos & all other material except Epoxy materials although this rise is very less numerically. Hence this maximum principal stress comparison plot shows that all the materials are suitable for Drive Shaft according to maximum principal stress criteria.

E. Shear Stress Pattern

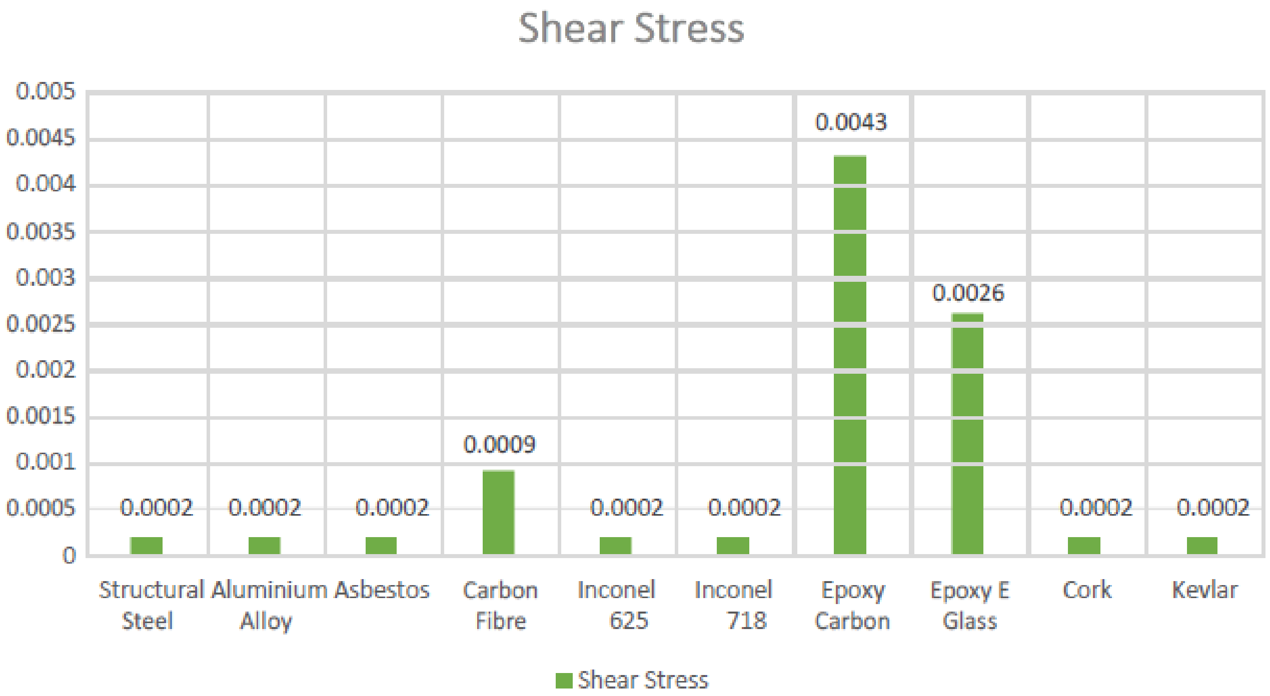


Fig. 5.5- Shear Stress Pattern

The plot of shear stress for all the materials have been plotted in above figure. Here one can clearly see that for structural steel, the shear stress of Drive Shaft is 0.0002 MPa which remain nearly equal for aluminium alloy, Asbestos, Inconel materials & Ceramics like Cork & Kevlar. It slightly rises to

0.0009 MPa in case of Carbon Fibre. After that for all Epoxy materials it increases to 0.0026 MPa & above. Hence this shear stress comparison plot shows that Aluminium alloy, Inconel materials, Ceramics and Asbestos are better suitable for Drive Shaft according to shear stress criteria.

F. Equivalent Elastic Strain Pattern

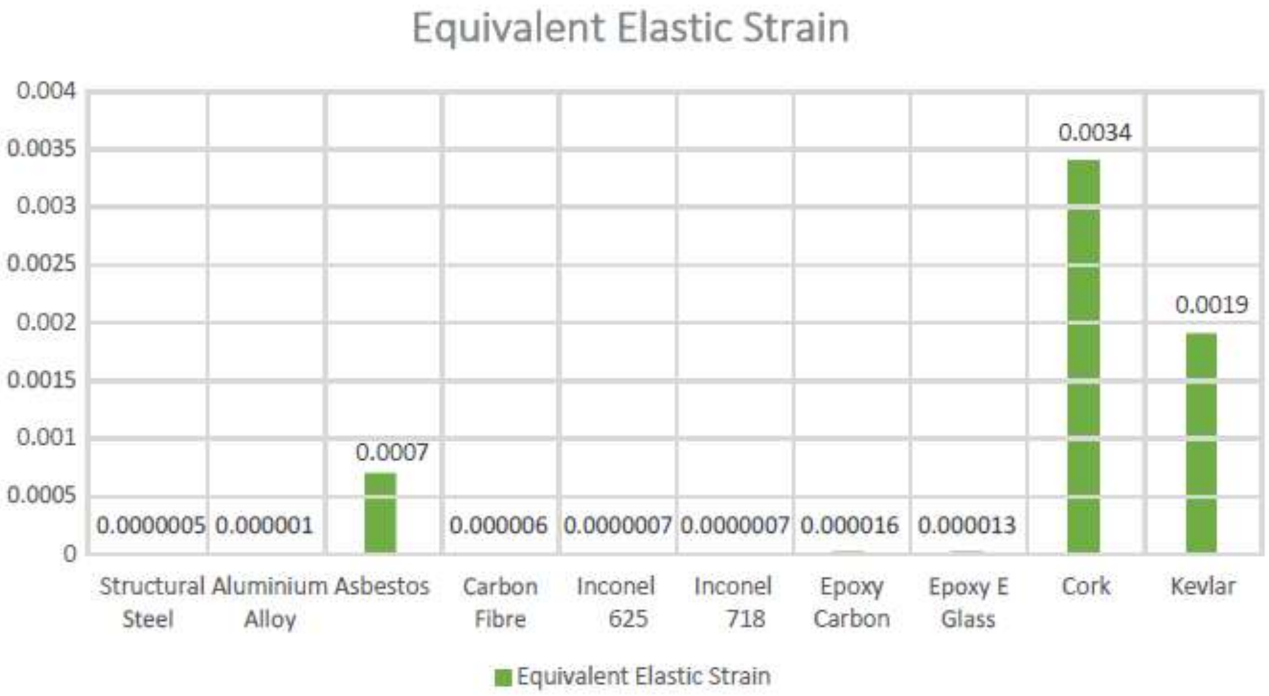


Fig. 5.6- Equivalent Elastic Strain Pattern

The plot of normal stress for all the materials have been plotted in above figure. Here one can clearly see that for structural steel, the Equivalent elastic strain of Drive Shaft is 0.0000005 mm/mm which increases for aluminium alloy and all other materials. For Inconel materials this increment is least and the overall equivalent elastic strain for Inconel materials is nearly equal to structural steel (conventional material). Hence this Equivalent Elastic Strain comparison plot shows that Inconel materials, Aluminium Alloy & composite materials can be used for the application for Drive Shaft according to this criterion as the increment in Equivalent Elastic Strain is less than even a single mm/mm.

G. Shear Elastic Strain Pattern

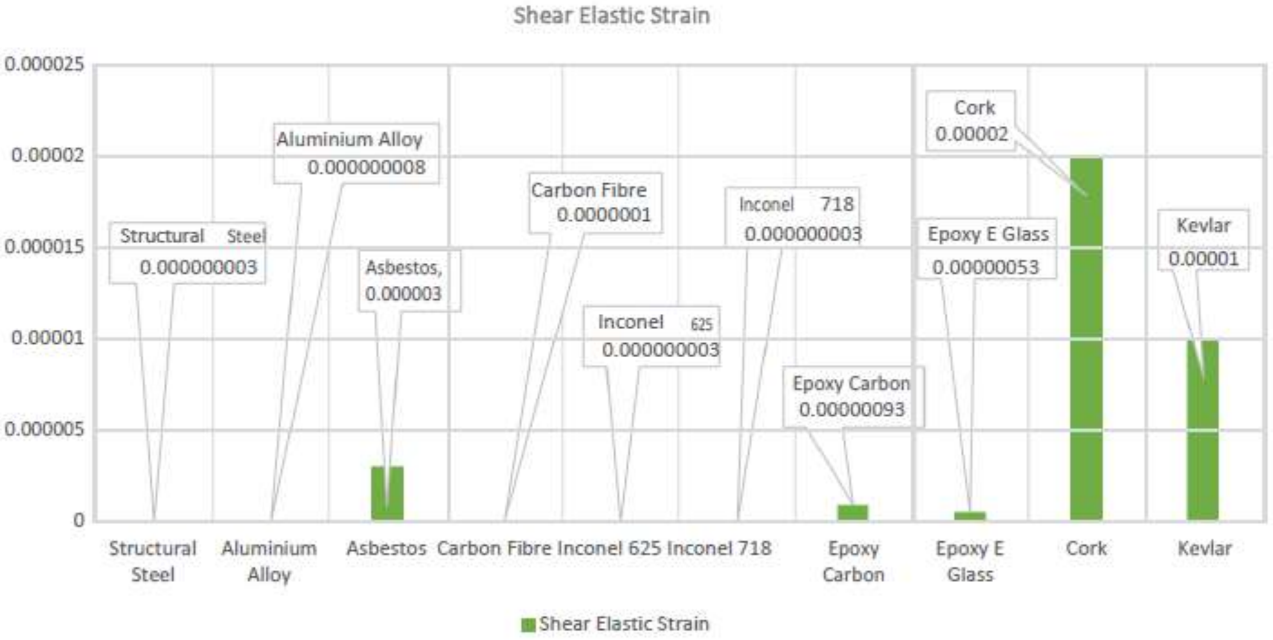


Fig. 5.7- Shear Elastic Strain Pattern

The plot of Shear Elastic Strain for all the materials have been plotted in above figure. Here one can clearly see that for Structural steel, the Shear Elastic Strain of Drive Shaft is 0.000000003 mm/mm which increases for aluminium alloy and all other materials except Inconel materials for which Shear Elastic Strain remains equal to conventional material. Hence this Shear Elastic Strain comparison plot shows that Inconel materials are better suitable for Drive Shaft according to this criterion.

6. Conclusion

After analysing the data all along until now following concluding points can be pointed out- Weight is reducing for aluminum alloy and all other composite materials except Inconel materials which shows that these all may be used for designing Drive Shafts. Total deformation is increasing in case of Inconel materials & all other materials & hence if these alternate materials are to be used for manufacturing Drive Shafts, they will cause more deformation although the increment is quite low numerically. Maximum principal stress remains same for Inconel materials, aluminum alloy and all other composite materials when compared to conventional material. Equivalent stress remains approximately equal for Inconel materials & all other materials which reveals that this component under given circumstances is not affected by the material much. Shear stress is reducing in case of Inconel materials, ceramics, Aluminum Alloy & Asbestos when compared with conventional material. Equivalent Elastic strain & Shear Elastic Strain also remains same in case of Inconel materials in comparison with conventional material. For all other materials, these values are increasing which reveals that Inconel materials are the most suitable alternate for conventional material for the given application. All the above criteria point to the conclusion that Inconel materials may be used for designing Drive Shafts & they will improve the performance of Drive Shafts when in work.

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