DESIGN AND MODEL ANALYSIS OF RAIL AXLE WITH VARIOUS COMPOSITE MATERIALS USING FEM

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Abstract: Axles are one of the most important railway vehicle parts that supports the weight of both vehicle and passenger. Generally train axle shaft is made up of steel, which requires more power to drive due to its more self weight. This research paper mainly focused on use of hybrid structure to achieve weight reduction and permissible strength compared to conventional structure. Use of advanced composite material such as Kevlar, boron and glass-fiber resulted in remarkable achievements because of its specific strength and improve fatigue, specific modulus and reduction in energy requirements due to reduction in weight as compared to steel axle. This paper presents the modeling and analysis of metal composite rail axle using Kevlar, boron, glass-E, glass-S and 30NiCrMoV12. The overall objective of this paper is to analyze the metal composite axle to find out the best replacement for conventional steel axle in terms of reduced energy requirements by reducing weight, comparing static behavior, and the natural frequency of both conventional rail axle and Metal composite rail axles when exposed to the same boundary and loading condition.

Key Words: Rail axle, composites, Finite Element Analysis.

Introduction

A train wheel or rail wheel is a type of wheel specially designed for use on rail tracks. A rolling component is typically pressed onto an axle and mounted directly on a rail car or locomotive or indirectly on a bogie, called a truck. Wheels are cast or forged (wrought) and are heat-treated to have a specific hardness. New wheels are trued, using a lathe, to a specific profile before being pressed onto an axle. All wheel profiles need to be periodically monitored to insure proper wheel-rail interface. Improperly trued wheels increase rolling resistance, reduce energy efficiency and may create unsafe operation. A railroad wheel typically consists of two main parts: the wheel itself, and the tyre around the outside. A rail tyre is usually made from steel, and is typically heated and pressed onto the wheel, where it remains firmly as it shrinks and cools. Mono block wheels do not have encircling tires, while resilient rail wheels have a resilient material, such as rubber, between the wheel and tire.

1.1 Rail axle: Rail axle is one of the important component of the rail vehicle which supports the weight of both passengers and vehicle.

1.2 Wheelset: A wheelset is the wheel - axle assembly of a railroad car. The frame assembly beneath each end of a railcar or locomotive that holds the wheelsets is called the bogie. Wheel set comprises two wheels rigidly connected by a common axle. The wheel set is supported on bearings mounted on the axle journals.

1.3 Axle box: The axle box is the device that allows the wheel set to rotate by providing the bearing housing and also the mountings for the primary suspension to attach the wheel set to the bogie or vehicle frame.

Fig 1.1 (a)Rail axle, (b)wheel set, (c)axle box

1.4 Composites: A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. Examples Reinforced concrete, ply wood, Fibre reinforced plastics , metal matrix composite etc.

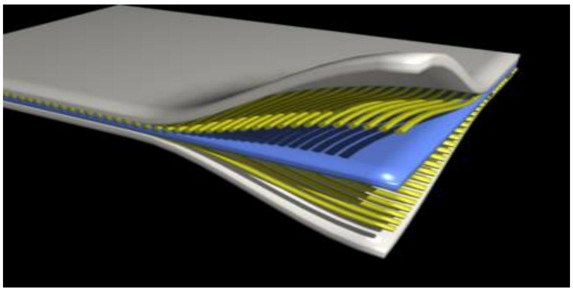


Fig 1.2 Composite material

1.5 Analytical calculations

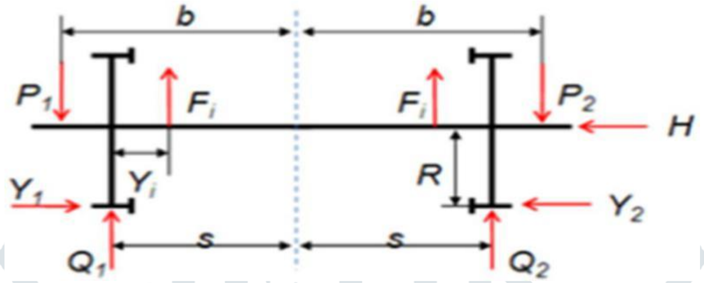


Fig. 1.3 Load case for the railway axle design (for static analysis)

Considering as an example at rail axle of non-tilting vehicle, the expressions for forces P acting on journals derive from an estimation of lateral acceleration equal to 0.15g, computed simultaneously with an increment on both journals of 25% of half the static load m1g acting on them.

Here,

- Weight(m)=13,960kg
- Height(h)=1425mm
- Distance from center(b)=1000mm
- Center distance from wheel(S)=750mm
- Force on wheel1(Y1)=47,932N
- Force on wheel2(Y2)=23,966N
- Load(P) = (0.625+0.0875*h/b)mg = 96879 N
- Load(Q) = [P(b+s)-P(Y1-Y2)R-Fi(2s-yi)]/2s = 101967 N

1. Design of Rail axle

In this study, dimensions of rail axle component are taken according to AAR (American association of Railroad).

Two designs have been considered, one for the conventional steel Axle and one for the composite structure. Conventional steel Axle was made of whole steel according to AAR standard. Composite Axle made of three bodies, one was outer hollow steel Axle with the length of 2159mm with varying thickness through length and inner diameter 90 mm. Second body was inner solid steel Axle which had same length 2159mm and diameter of 30 mm. And third body was composite body with thickness of30mm and inner diameter of 30 mm,2159mmlength.

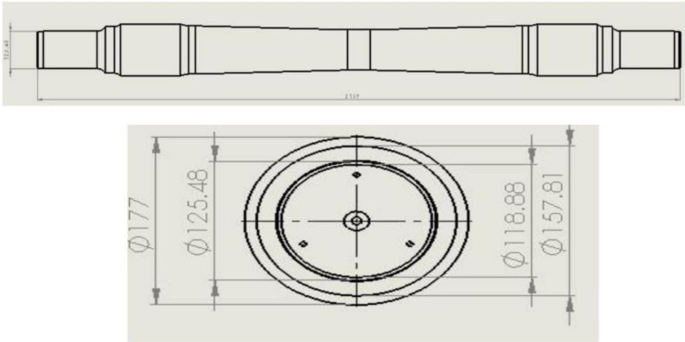


Fig 2.1 Specifications of a rail

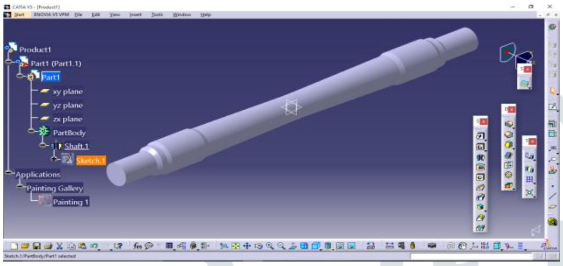


Fig. 2.2 Model of conventional rail axle

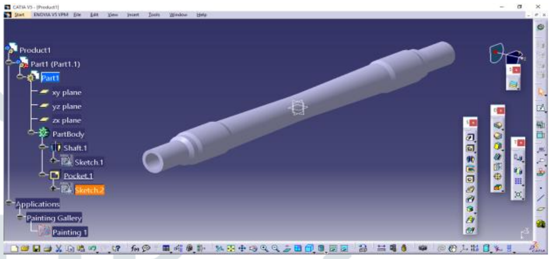


Fig. 2.3 Model of outer rail axle

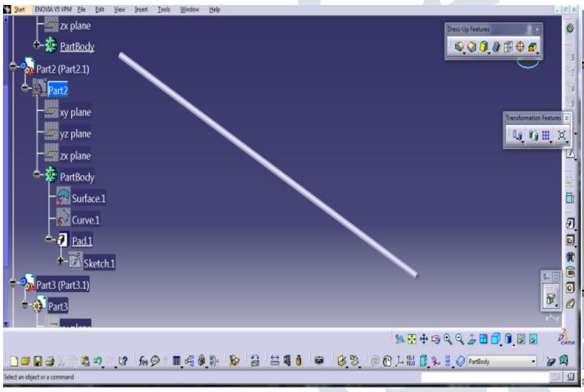


Fig. 2.4 Model of inner rail axle

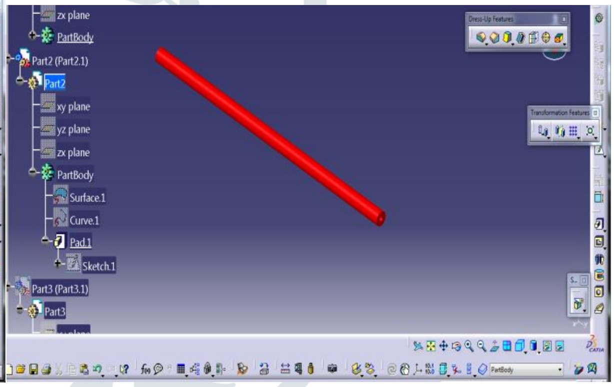


Fig.2.5 Model of composite axle

composite model is like hollow shaft with 30mm inner diameter and 30 mm thickness is used for the composite model.

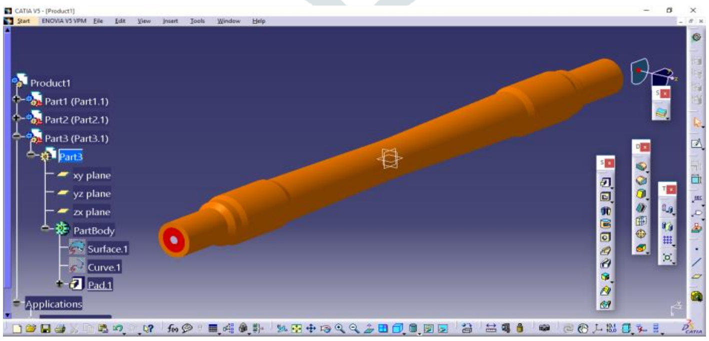


Fig. 2.6 Model of composite axle assembly

2. Methodology

3.1 Finite Element Analysis

The FEM is numerical analysis technique for obtaining approximate solutions to wide variety of engineering problems. The method originated in the aerospace industry as a tool to study stresses in complicated air frame structures. It grew out of what was called the matrix analysis method used in aircraft design. The method has gained popularity among both researchers and practitioners and after so many developments codes are developed for wide variety of problems.

3.2Material Properties

Composite materials have different structural properties. One of the materials, called the reinforcing phase is embedded in the other material of the matrix phase. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The main advantage of composite materials is the potential for a high ratio of strength to weight. Composites used for typical engineering applications are advanced fiber or laminated composites, such as fiber glass, glass epoxy, graphite epoxy and boron epoxy. In this paper investigated composite materials are: Kevlar, boron, Glass E and Glass S. Conventional material that used was 30NiCrMoV12.

Table 3.1 Material properties

MATERIAL PROPERTIES	30NiCrMoV12 steel	KEVLAR	BORON	GLASS-E	GLASS-S
Density(Kg/m3)	8900	1470	2370	2540	2540
Elastic modulus (GPa)	180	175	60	76	88

3.3 Applying Loads and Boundary Conditions:

Here the force applied on the both the ends where bearing is being mounted in downward direction and another force applied in opposite direction on wheel sheets which is being coming from the track. Two forces of 97KN applies at both ends in downward direction and two forces of 100KN applied in upward direction on wheel sheets. This force is measured by AAR which is for the static analysis of Rail axle.

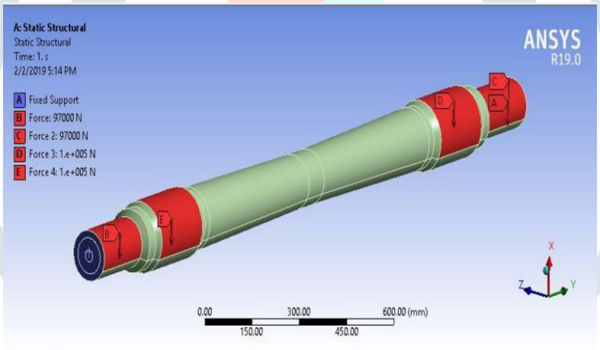
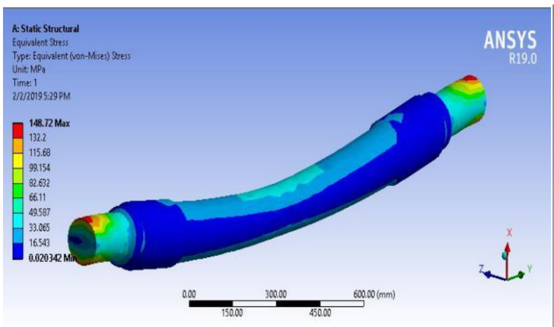


Fig.3.1 Loads and Boundary conditions

4. Linear Static Stress Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS, Samcef, or ABAQUS solver.

Static analysis is being carried out in ANSYS V19. First solid conventional steel axle model and metal-composite structure brought to ANSYS V19. Material properties inserted into the engineering data. Then deformation and stress are being calculated.



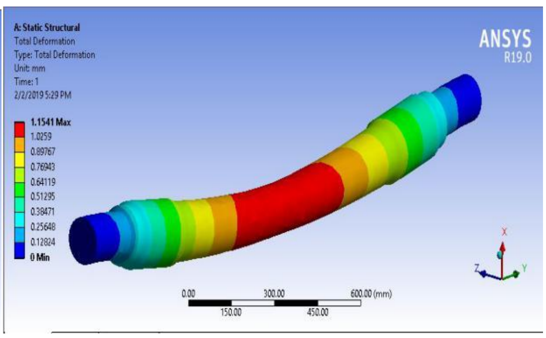


Fig 4.1Von-Mises stress for Conventional steel Fig 4.2Total deformation for Conventional steel

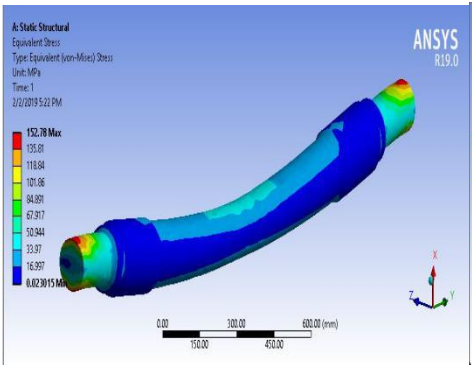


Fig 4.3Von-Mises stress for Kevlar

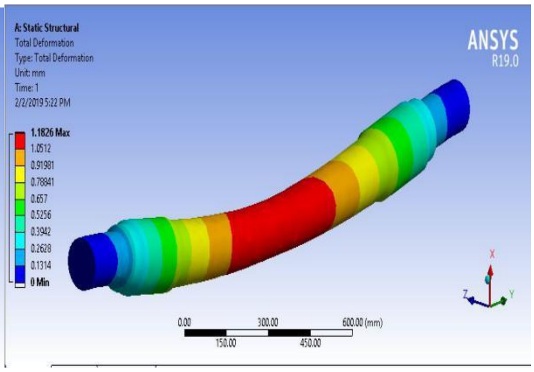


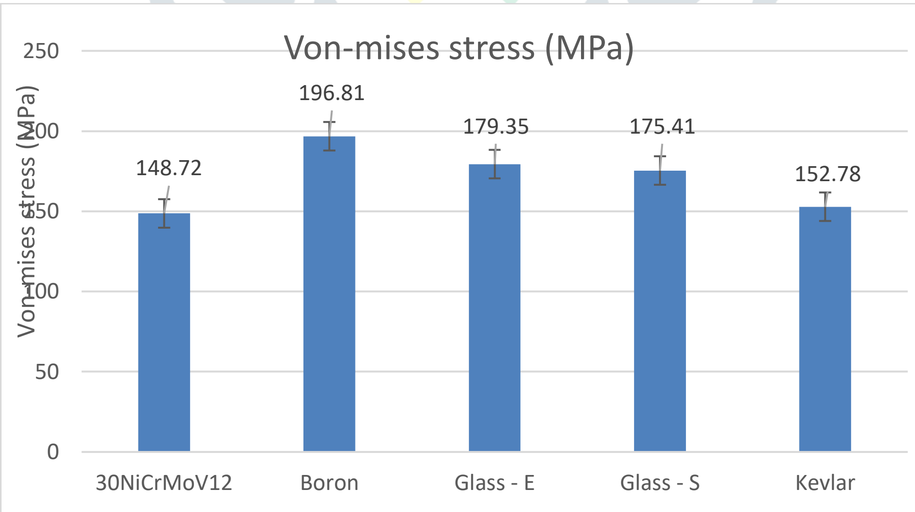
Fig 4.4Total deformation for Kevlar

4.1 Rail axle static Analysis Results:

In the current investigation stress and deformation for different rail axle are found.

Table 4.1 von-mises stress values (Mpa)

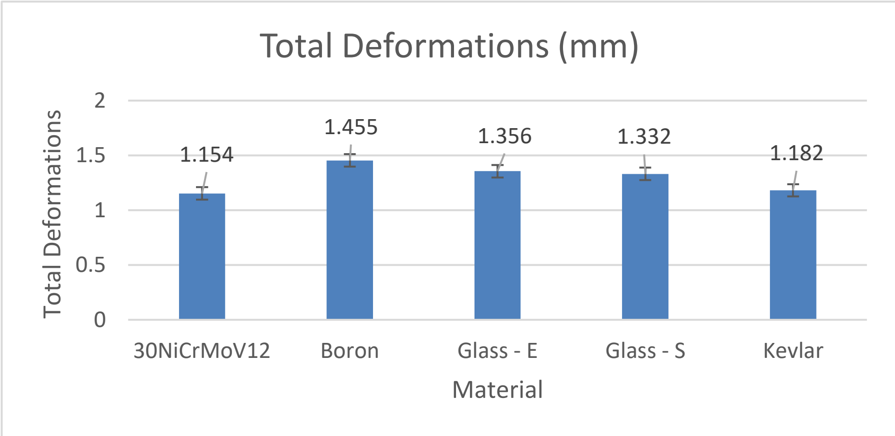
Materials	Von-mises stress (MPa)
30NiCrMoV12	148.72
Boron	196.81
Glass - E	179.35
Glass - S	175.41
Kevlar	152.78



Graph4.1 von-mises stress

Table 4.2 Total Displacement values

Materials	Total Deformations (mm)
30NiCrMoV12	1.154
Boron	1.455
Glass - E	1.356
Glass - S	1.332
Kevlar	1.182



Graph4.2 Total Displacement

5. Model analysis

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a seismic analysis.

Natural frequency is the frequency at which a system naturally vibrates once it has been set into motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position, if there is no outside interference.

5.1 Mode shapes: For every natural frequency there is a corresponding vibration mode shape. Most mode shapes can generally be described as being an axial mode, torsion mode, bending mode, or general modes. A crude mesh will give accurate frequency values, but not accurate stress values. Modal analysis was carried out on Rail wheel axle to determine the natural frequencies and mode shapes of a structure in the frequency range of 0 to 1000 Hz.

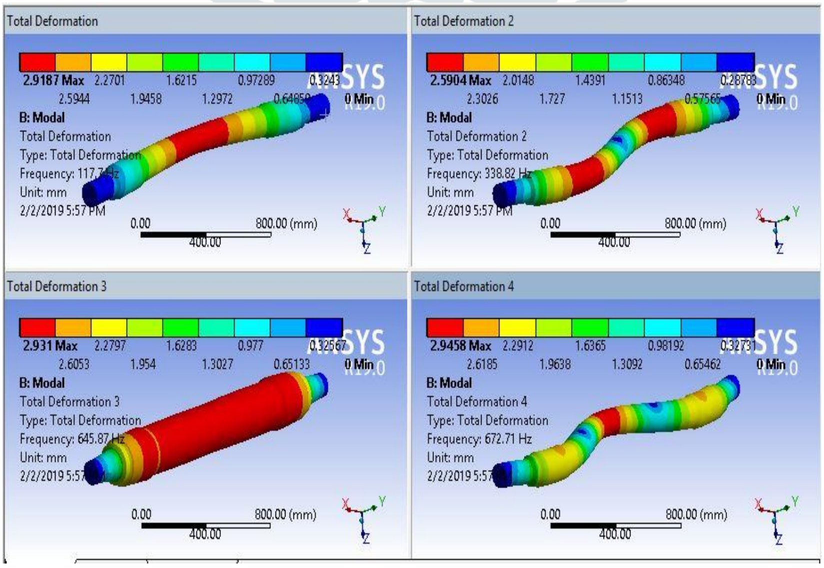


Fig.5.1 Mode shapes of Conventional steel axle

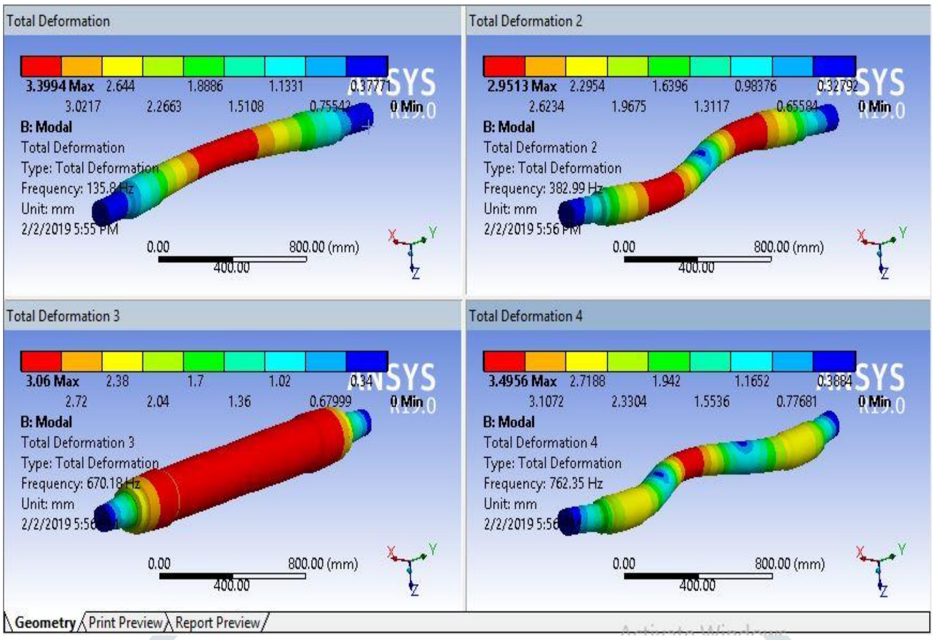
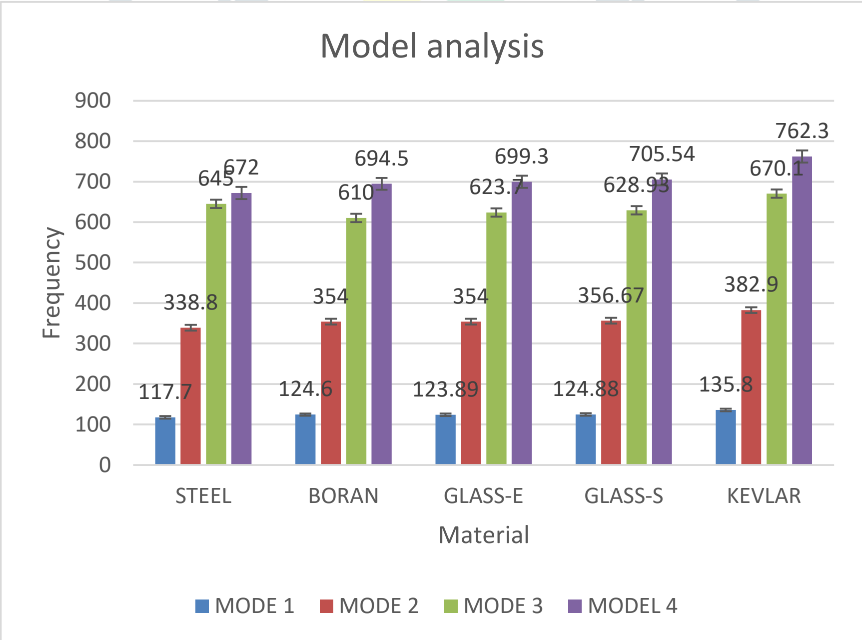


Fig.5.2 Mode shapes of Metal - Kevlar axle

Table.5.1 Frequencies obtained from model analysis

	STEEL	BORAN	GLASS-E	GLASS-S	KEVLAR
MODE 1	117.7	124.6	123.89	124.88	135.8
MODE 2	338.8	354	354	356.67	382.9
MODE 3	645	610	623.7	628.93	670.1
MODE 4	672	694.5	699.3	705.54	762.3



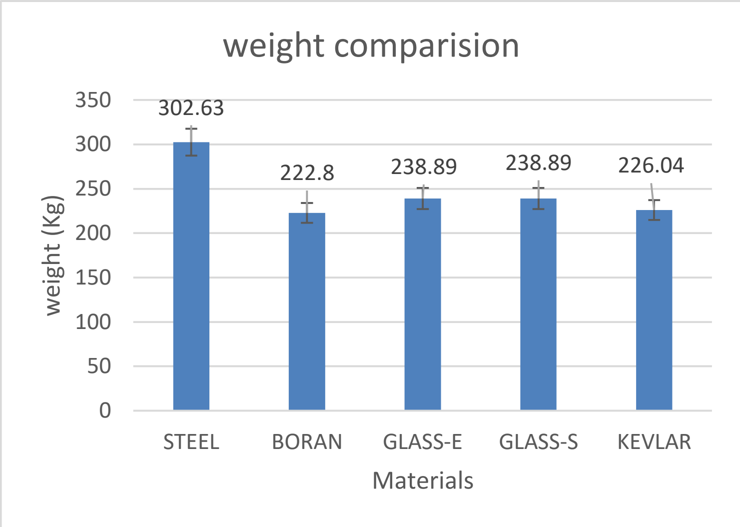
Graph.5.1 Model analysis results

6. Weight comparison

Volume of all considered axles is same i.e. Volume = 3.8552e+007mm

Table6.1 Weight of rail axles

Material	STEEL	BORAN	GLASS-E	GLASS-S	KEVLAR
Weight (Kg)	302.63	222.8	238.89	238.89	226.04



Graph6.1 Weight comparison.

Conclusions

- Generally train axle shaft is made up of steel, which requires more power to drive due to its more self weight. In present work composite materials are used for train axle shaft due to their high strength to weight ratio.
- Composite materials are having less wear resistance that's why 30mm composite layer thickness is placed between steel solid pipes i.e, sealed inside of steel tubes.
- Structural analysis is performed on this axle shaft by considering the cabin weight and wheel reaction. Outer steel pipe having more stress as compared to composite and inner shaft. weight comparison has done and observed as composite materials are 25%lessin weight as compared to steel material.
- From the modal analysis it is observed that the axle with kevlar material has more natural frequencies as compared to remaining materials.
- From all the materials used in this work, Kevlar epoxy fiber material is optimum suitable for train axle. according to structural strength, vibration and damping factor all materials results are in allowable limit.

Future Scope for Study

By optimizing composite material thickness better results can be achieved. Rail Car body and parts can be made from composites to reduce the overall weight of the vehicle.

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