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Strength-to-Weight Optimization of Driver Shafts: A Comparative Analysis of Material Selection, Manufacturing Methods, Generative Design, and Topology Optimization using Fusion 360

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Abstract - This study presents a comprehensive comparative analysis of strategies for optimizing the strength-to-weight ratio of driver shafts in automobile applications. The research focuses on four key areas: material selection, manufacturing methods, generative design, and topology optimization.

Firstly, a range of materials commonly used in driver shaft manufacturing is evaluated, considering factors such as strength, weight, durability.. Various manufacturing methods, including traditional techniques and advanced processes like additive manufacturing, are assessed for their impact on shaft performance.

The study also delves into the application of generative design and topology optimization techniques. Generative design algorithms are employed to explore innovative shaft geometries that enhance structural integrity while minimizing weight. Topology optimization algorithms are utilized to optimize material distribution within the shaft, further improving strength-to-weight characteristics.

The findings highlight the potential benefits of integrating advanced design methodologies with appropriate material selection and manufacturing processes. This research contributes valuable insights for optimizing driver shafts, enhancing automobile performance, and achieving efficient utilization of materials in automotive engineering.

Key Words: Driver Shaft design, Strength and weight optimization, Generative Design, Topology Optimization, Material and manufacturing Consideration.

1.INTRODUCTION

The development of driver shafts for automobile applications has witnessed significant advancements driven by the pursuit of optimal strength-to-weight ratios. A critical aspect of this evolution lies in the integration of advanced design methodologies, material selection, and manufacturing techniques. In this context, the focus shifts towards exploring the potential of generative design and topology optimization to enhance the performance and efficiency of driver shafts made from a single piece.

The materials landscape for driver shafts encompasses a diverse range of options, each with distinct mechanical properties and suitability for specific applications. This study considers a comprehensive set of materials, including ABS plastic, aluminum 6061, aluminum AlSi10, cobalt chrome, GFRP (Glass Fiber Reinforced Polymer), HP 3D HR CB PA12, Inconel 625, nylon 6/6, PEKK (Polyetherketoneketone reinforced with carbon fibers), stainless steel AISI 304, among others. These materials represent a spectrum of characteristics such as strength, weight, durability, and cost-effectiveness, crucial factors in the optimization process.

Generative design emerges as a key enabler in this endeavor, offering the capability to explore complex geometries and structural configurations that traditional design approaches may overlook. By leveraging generative design algorithms, novel shaft designs can be generated, aiming to strike an optimal balance between structural integrity and weight reduction.

Topology optimization complements generative design by optimizing material distribution within the shaft's structure. This approach aims to remove excess material where it's not needed, leading to further weight savings without compromising strength or performance.

The integration of these methodologies presents a promising avenue for achieving superior strength-to-weight ratios in driver shafts, aligning with the automotive industry's demand for lightweight yet robust components. Through a comparative analysis encompassing material properties, manufacturing considerations, generative design outcomes, and topology optimization results, this study aims to provide valuable insights into the optimization of driver shafts for enhanced automobile performance and efficiency. [1].

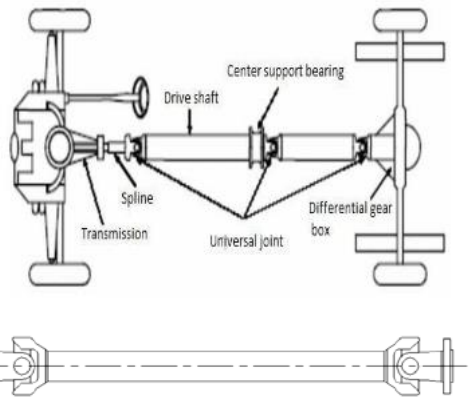

Fig -1: Design of Drive Shaft in vehicle. [2].

2. LITERATURE SURVEY:

Review of Design of Hybrid Metals/Polymers Drive Shaft for Automobile

Different Hybrid Metals/Polymers drive shafts are designed to replace an automobile's existing(steel) drive shaft. One-piece hybrid Metals/Polymers drive shafts for rear-wheel drive cars have been produced with the goal of reducing the shaft's

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weight. Limitations including torque transmission, natural bending frequency, and torsional buckling capacities were applied to this shaft. The fundamental natural frequency and static torque capabilities were higher than the design specifications, coming in at 9390 rpm and 4320 Nm, respectively. [1][3].

Review of Evaluation of Topology Optimization and Generative Design Tools as Support for Conceptual Design

Autogenetic Design Theory was developed in the field of engineering design, where researchers looked at the parallels between the natural process of evolution and the design process that is a part of the product development process. "The evolutionary view describes the product development process as a continuous optimization of a basic solution by observing starting conditions, boundary conditions, and constraints,". These elements set up the design space and have an impact on design evolution. One way to conceptualize generative design is as an approach to multi-design production that incorporates both automation and autonomy. The design process is approached using nature's evolutionary method. It begins with one or more distinct designs dispersed throughout the design space, which over time transform into shapes more suited to the circumstances. Designs that don't work or don't meet the design objectives are thrown out, and the process of evolution keeps going in different directions. Generative design is typically related to the use of algorithms as a basis for design creation. Recently generative design tools have been introduced as separate modules in a number of commercial CAD software's for engineering design. Generative design tools are initially based on algorithms used in topology optimization, namely the level set method (LSM). They operate with moving boundaries instead of local density variables, therefore they have the ability to be mesh-independent thus having different requirements for design setup than topology optimization. [4].

Review of Difference Between Topology Optimization and Generative Design

Topology optimization (TO) is a mathematical technique that optimizes the spatial distribution of material inside a given area by meeting predefined criteria and minimizing a predefined cost function. The three main elements of this optimization process are the cost function, the constraint, and the design variables. Even though topology-optimized designs satisfy all design requirements, they might be too costly or impractical to build with traditional manufacturing technology. For this reason, even though the concept of TO has been around for the past thirty years, it has not been widely used for subtractive manufacturing. The complexity that AM provides has made it possible to manufacture TO parts. [5].

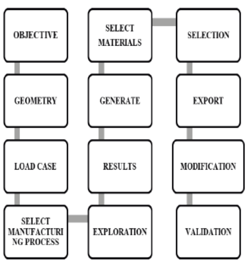

Fig-2: Workflow of Autodesk Generative Design.[5]

3. PROBLEM DEFINITION

The problem addressed in this study is the optimization of driver shafts for automobile applications using generative design techniques. The primary challenge is to achieve an optimal balance between strength and weight, ensuring that the driver shafts exhibit superior performance while minimizing material usage and overall weight.

3.1 Optimal Strength-to-Weight Ratio: The objective is to design driver shafts that maximize their strength-to-weight ratio for different materials, ensuring structural integrity and performance while minimizing unnecessary material usage.

3.2 Material Selection: The problem includes selecting the most suitable materials for generative design optimization, considering factors such as mechanical properties, manufacturability. In this case ABS plastic, Aluminum 6061, Aluminum AlSi10, cobalt chrome, GFRP (Glass Fiber Reinforced Polymer), HP 3D HR CB PA12, Inconel 625, nylon 6/6, PEKK (Polyetherketoneketone reinforced with carbon fibers), stainless steel AISI 304 considered for analysis.

3.3 Generative Design Exploration: Utilizing generative design algorithms to explore a vast design space and generate innovative shaft geometries that enhance performance characteristics.

3.4 Integration with Manufacturing Constraints: Integrating generative design outcomes with manufacturing constraints and processes, ensuring that the optimized designs are feasible for production using appropriate techniques such as additive manufacturing or traditional machining.

4. METHODS

1. Modeling of implant & surrounding bone

The 3D Model of Propeller Shaft is done using Solid works which enables design automation and product development processes and thereby brings about an optimum design.

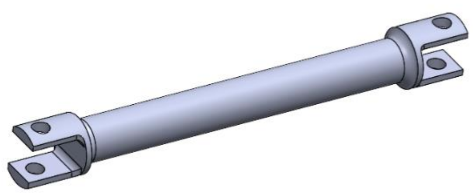

Fig-3: 3D model of Drive Shaft

Model Dimensions as below,
Length – 400mm, OD – 36mm, Solid shaft considered.
In this study, the mechanical properties of the propeller shaft are treated to be homogenous, isotropic and linear elastic. Selected Materials and properties as shown in table-1, [6].

Material Properties			
Fig-4	ABS	Fig-9	HP 3D HR CB PA12
Fig-5	Aluminum 6061	Fig-10	Inconel 625
Fig-6	Aluminum AlSi10	Fig-11	nylon 6/6
Fig-7	cobalt chrome	Fig-12	PEKK
Fig-8	GFRP	Fig-13	stainless steel AISI 304

Table-1: Material considered for Design Optimization

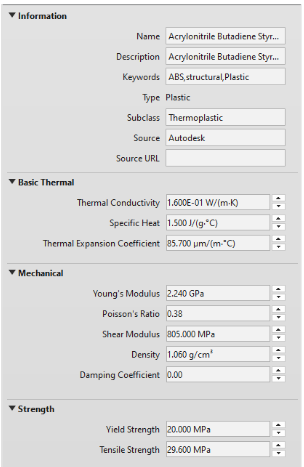

Fig-4: ABS

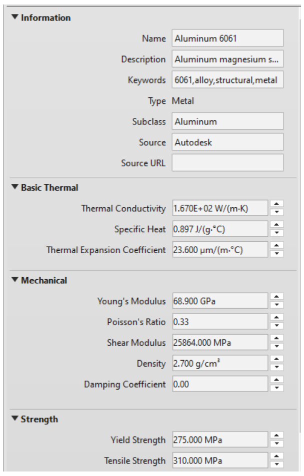

Fig-5: Al 6061

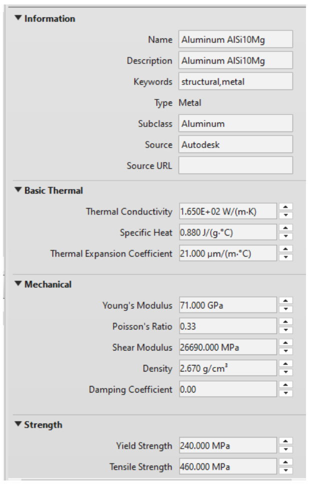

Fig-6: Al AlSi10

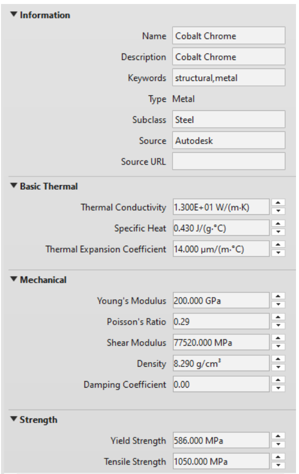

Fig-7: cobalt chrome

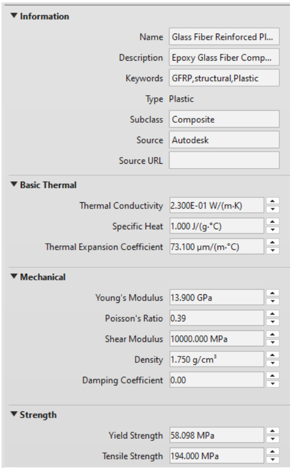

Fig-8: GFRP

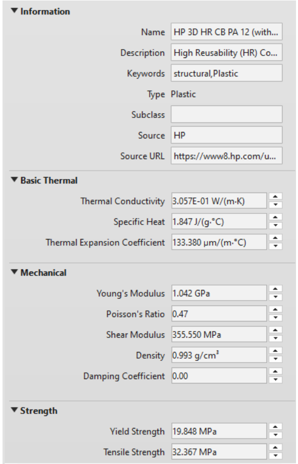

Fig-9: HP 3D HR CB PA12

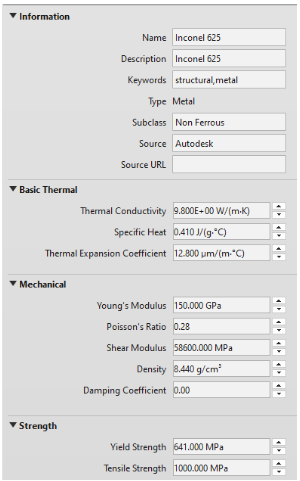

Fig-10: Inconel 625

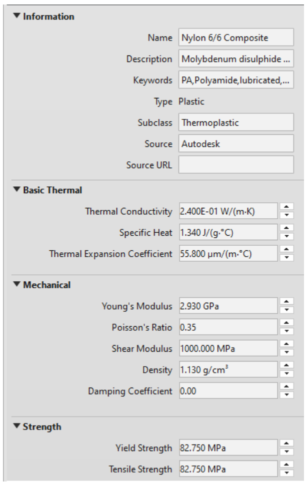

Fig-11: nylon 6/6

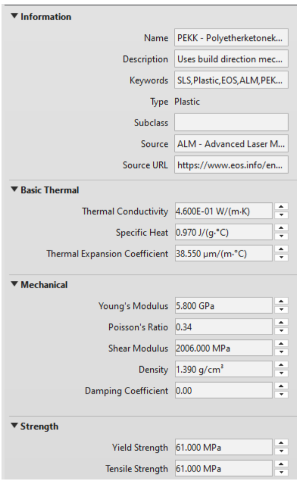

Fig-12: PEKK

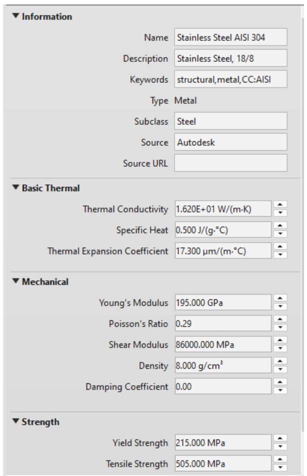

Fig-13: stainless steel AISI 304

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2. Generative Design Model

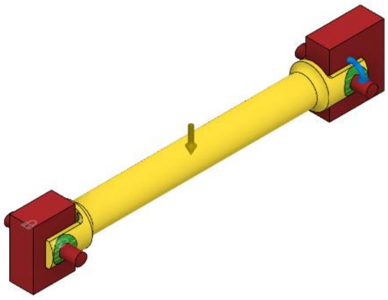

Fig-14: Generative design Boundaries

Above Model representing the Preserve Geometry, Obstacle Geometry, Starting shape.

3. Loading and Boundary conditions

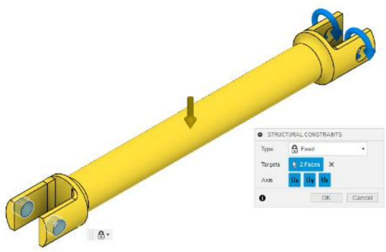

Fig-15: Boundary condition of Drive shaft

The Gearbox is on action in maximum load condition for a shaft at which the differential (Wheel) movement is arrested. Three boundary conditions are been applied in a Moment of 15100 N-mm.

4. Selection of Manufacturing Method for Drive shaft

Table -3: Strength and Weight(mass) for Additive material

Additive	Yield Strength (Mpa)	Initial Weight/Mass (Kg)
ABS	20	0.38
GFRP	58.098	0.64
nylon 6/6	82.750	0.41
PEKK	61	0.51
HP 3D HR CB PA12	19.84	0.36
Aluminum AlSi10	240	0.98

Table -4: Strength and Weight(mass) for Milling material

Milling	Yield Strength (Mpa)	Initial Weight/Mass (Kg)
Aluminum 6061	275	0.99
cobalt chrome	586	3.04
stainless steel AISI 304	215	2.94
Inconel 625	641	3.10

For this Analysis Objective considered as minimize the mass and Targeted Factor of safety is 3.

5. Exploring the Generative Results

Equivalent Stress and Total deformation are been considered for evaluating the results in the current Generative and Topology optimization study.

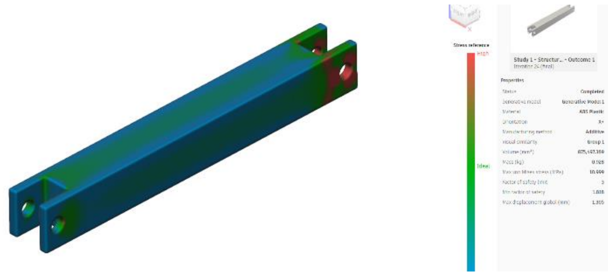

Fig-16: ABS Drive Shaft stress and displacement

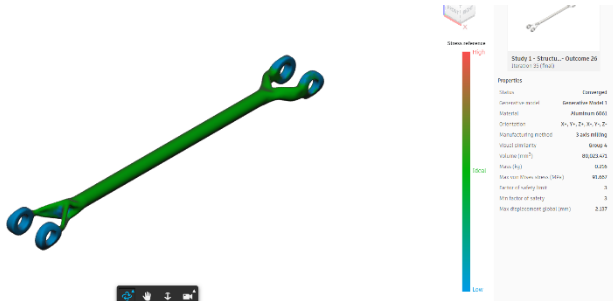

Fig-17: AL 6061 Drive Shaft stress and displacement

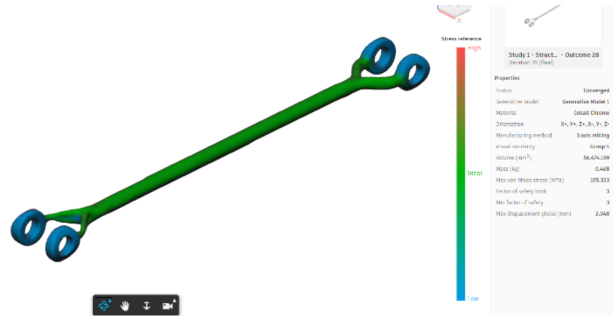

Fig-18: Cobalt Chrome Drive Shaft stress and displacement

Fig-19: GFRP Drive Shaft stress and displacement

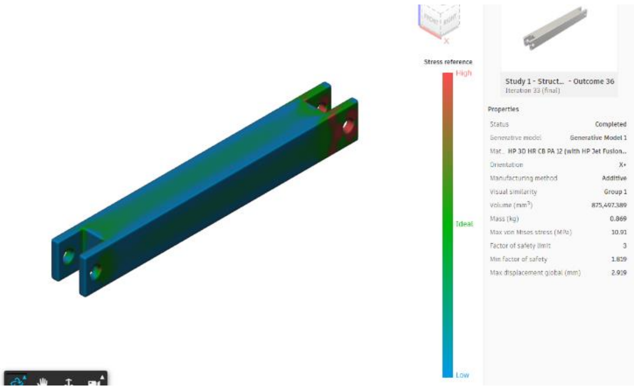

Fig-20: HP 3D HR CB PA12 Drive Shaft stress and displacement

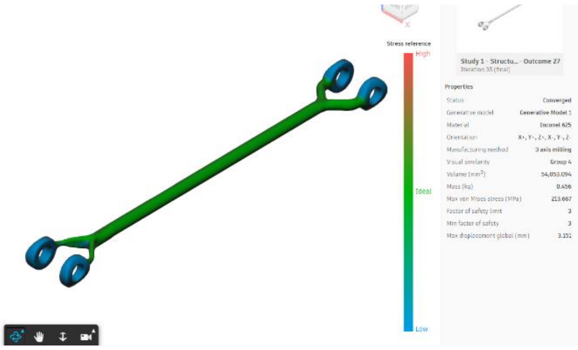

Fig-21: Inconel 625 Drive Shaft stress and displacement

Fig-22: nylon 6/6 Drive Shaft stress and displacement

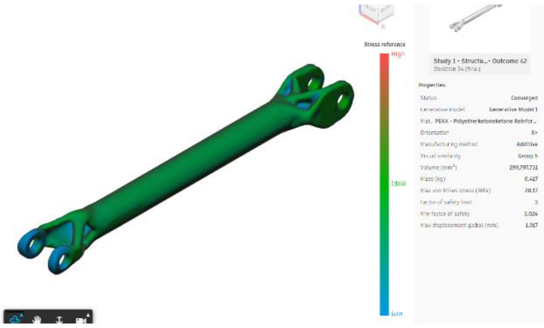

Fig-23: PEKK Drive Shaft stress and displacement

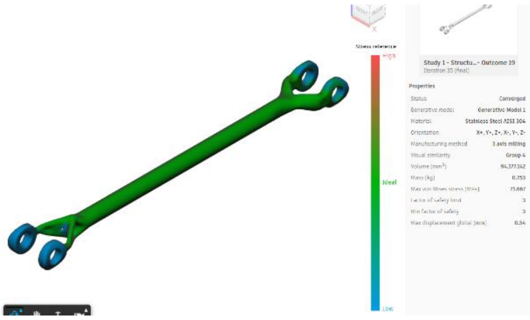

Fig-24: stainless steel AISI 304 Drive Shaft stress and displacement

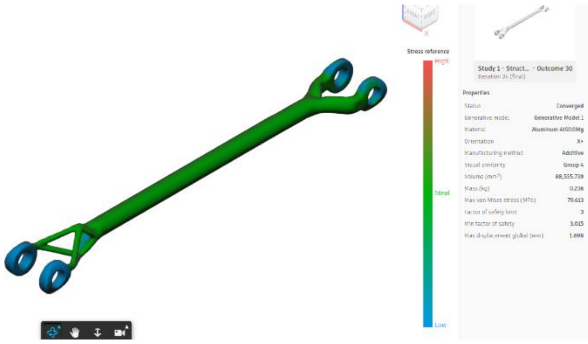

Fig-25: Aluminum AlSi10 Drive Shaft stress and displacement

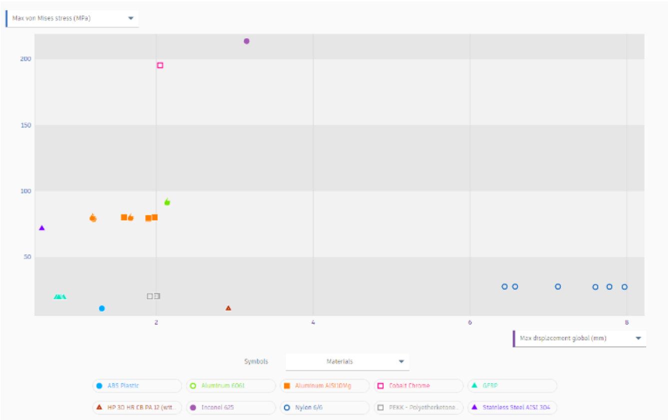

Chart-1: Max.Von mises stress(Mpa) V/s Max. Displacement(mm) for materials

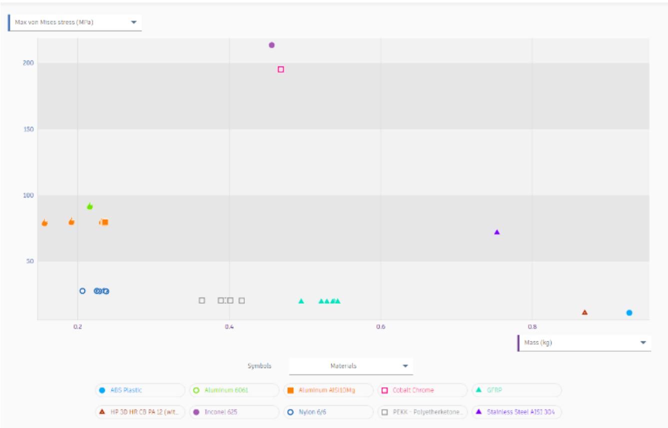

Chart-2: Max.Von mises stress(Mpa) V/s Mass(Kg) for materials

Topology Optimization Results for stainless steel AISI 304

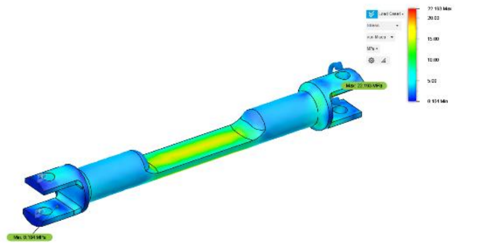

Fig-26: Stress: Topology Optimization of SS AISI 304

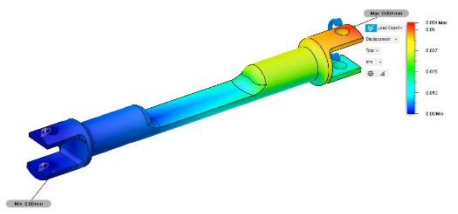

Fig-27: Displacement: Topology Optimization of SS AISI 304

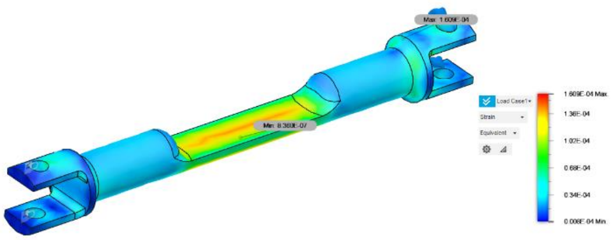

Fig-28: Strain: Topology Optimization of SS AISI 304

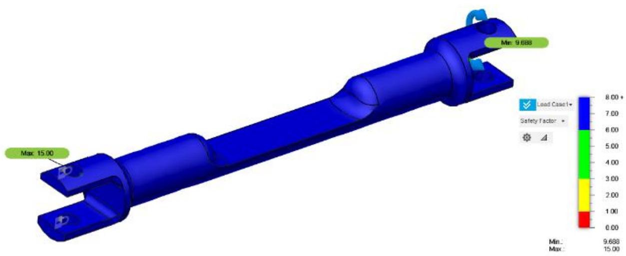

Fig-29: FOS: Topology Optimization of SS AISI 304

Table -5: Result table for Generative Design

material	Manufacturing Method	Equivalent stress (Mpa)	Max. Displacement(mm)	Optimized Mass (Kg)	FOS Achieved
ABS	Additive	10.99	1.305	0.928	1.8
GFRP	Additive	19.36	0.816	0.539	3
nylon 6/6	Additive	27.23	7.6	0.238	3
PEKK	Additive	20.17	1.917	0.417	3
HP 3D HR CB PA12	Additive	10.91	2.919	0.869	1.819
Aluminum 6061	Milling	91.66	2.137	0.216	3
Aluminum AlSi10	Additive	79.61	1.898	0.236	3
cobalt chrome	Milling	195.33	2.048	0.468	3
stainless steel AISI 304	Milling	71.66	0.54	0.753	3
Inconel 625	Milling	213.66	3.151	0.456	3

Table -6: Result table for Topology Optimization

material	Manufacturing Method	Equivalent stress (Mpa)	Max. Displacement(mm)	Optimized Mass (Kg)	FOS Achieved
SS AISI 304	Milling	22.19	0.054	2.285	15

6. CONCLUSIONS

1. Generative Design of ABS(Additive), HP 3D HR CB PA12(Additive), nylon 6/6(Additive), material with manufacturing method is not meeting the Drive Shaft requirement of Strength to weight Optimization.
2. Generative Design of Al 6061(Milling), Cobalt chrome(Milling), GFRP(Additive), Inconel 625 (Milling), PEKK(Additive), stainless steel AISI 304 material (Milling), Aluminum AlSi10(Additive) with manufacturing method is meeting the Drive Shaft requirement of Strength to weight Optimization.

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BIOGRAPHIES

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