Topology Optimization for Designing a Wheel Rim

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1 Introduction

Automobiles play an important role in our day-to-day life. Automobile parts are made from various manufacturing components and we strive for making highly efficient component always. Traditionally these components are processed by casting and forging. Even after the development in manufacturing technology these processes are still used due to its strong efficacy. The advancement can be done in the area of design for the betterment of the manufacturing components by using optimization tools. One of such tools is the topology optimization which is an emerging field and is often used in early phase of conceptualizing designs, which in turn is used to determine the optimal approach of material distribution within the given design domain. Topology is derived from a Greek word "*Topos*" which means location, space, or domain. Optimization intends to obtain best alternative design that satisfies all the required criterion for a specified objective. Topology optimization aims to provide the best alternative of material configuration by reducing the weight without compromising the functioning of the component. The four-wheel automobiles are extensively used in day-to-day life due to its ability to carry loads, among which cars are at high demand due to the versatile comfort that it offers to a passenger as per their needs. A reason for these advantages lies on to the wheels that transmits the

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load uniformly. The different types of loads that it experiences are: static load (due to chassis), dynamic load (due to movement of vehicle), impact load (due to collision of vehicle), inertial load (due to breaks), and momentary duration load (due to vehicle turn). Hence, it is very important to perform topology optimization of wheels and static load is considered as the first step in this direction.

2 Related Literature

Alonso et al. [1] provided an advanced and integrated approach for collaborative multidisciplinary design that included consistent interdisciplinary analysis as well as multi-objective optimization of wing semi-span, outer wing, and sweep angle. They greatly enhanced the design, validating the industry's belief that multidisciplinary design optimization is critical for improving plans to meet market demands. The distinct hybrid optimization methods for optimal multi-objective low thrust spaceship trajectories and earth mass trajectories were discussed by Carroll et al. [2]. Wang et al. [3] used two separate strategies topology optimization and sizing optimization, to increase the stiffness of an automobile. Harzheim and Graf [4] did a review of optimization for casted parts and topology optimization was done for the same. Using a compromise programming technique, Xiao et al. [5] optimize the topology of steel wheel under static load conditions for eight distinct types of models to obtain maximum stiffness or minimal compliance. When compared to its original design, the optimized wheel disc does have a mass decrease 4.57%. Zhang et al. [6] described the Static analysis of finite element analysis of foundation construction, which is used to determine how the structures respond to specified limitations under different load. Christensen et al. [7] developed a model in Catia and imported it to Ansys, where they implemented various forms of boundary conditions. After performing crash simulation studies, the body in white (BIW) was optimized in two primary areas: overall topology and mass reduction. The impact of proposed revisions to the FMVSS 216 standard on the roof topology of a body in white for hybrid electric vehicle was investigated in this study. Li et al. [8] created an optimized 3-D suspension model. The model's strength, stiffness, and safety factor were then simulated and verified under three different conditions: turning, braking, and sharp turning. The suspension front upright's basic geometry model was optimized for weight reduction, resulting in a lightweight front upright with a mass reduction of 60.43%. The wheel's CAD model was made using the parameters, and the model was then simulated in Hypermesh, using standard load conditions (radial loads and bending loads). In one of the other works, Razak and Ikhwan [9] achieved weight reduction by using aluminum and magnesium alloy instead of steel and cast iron.

3 Problem Definition and Formulation

The wheel is a cylindrical component that rotates around an axle bearing and is one of the simple machines. The wheels and axles allow heavy things to be moved more readily, allowing for easier mobility or transit while sustaining defined loadings. The excessive weight of the wheel would demand more power from the engine, which may reduce the vehicle performance. The aim of this work is to obtain an optimal design of a wheel rim using topology optimization techniques by applying two different loading conditions for two different materials viz, aluminum and steel. These material configurations are chosen as these are commonly used for manufacturing components. The wheels are essential to the vehicle's safety, and they require careful attention to preserve their life. The development of the automobile industry is largely impacted by the wheel design, material selection, and manufacturing methods. They are loaded in a complex manner, and better understanding of these loadings would enable further refinements to produce an efficient wheel design. Two requirements must be met to achieve the best possible wheel design: precise knowledge of the material's loading, mechanical properties, and permitted stresses, which are influenced by vehicle attributes, service circumstances, and manufacturing methods. It would matter less, if you have highly efficient engine, but the wheel is very heavy and using all the available power to move its own weight. Therefore, it is a requirement to optimize the wheel design, so that better efficiency can be achieved in the given design domain.

4 Methodology

Topology optimization can be performed on various simulation platforms such as Fusion 360, Alter inspire, Creo 6.0, Siemens NX, Opti struct, Ansys, etc. The present optimization is done on Fusion 360, which is a multi-component part system that includes tools for parametric, direct, and mesh modeling. It is also completely cloud-based, making it ideal for distant teams. The different functionalities are separated into distinct workspaces, so the entire screen changes depending on the activity at hand (CAM, rendering, etc.), eliminating unnecessary space by removing unnecessary tools and features. Fusion 360 offers easy simulation packages that may be more beneficial in the early stages of the design to better understand how parts would react under different situations.

4.1 Materials Used

The wheel is manufactured by using casting technique. Casting is the process of pouring hot molten metal into the mold to get the desired shape. In the twenty-first

Table 1 Material properties of steel and aluminum

Material	Steel	Aluminum
Density (kg/mm^3)	7.85E−06	2.7E−06
Initial weight of specimen (kg)	61.848	20.874
Youngs modulus (GPa)	210	68.9
Poisons ratio	0.3	0.33
Yield strength (MPa)	207	275
Ultimate tensile strength (MPa)	345	310

century with the advancements in technology, new materials have been invented with different combination of alloys, ceramics, and natural composites. However, in this work we have used only the basis materials viz., aluminum and steel, as they are more readily available in workshops, making it ideal for this study. The properties of these materials are shown in Table 1. Steel is an iron alloy with a percent of carbon added to improve the material's strength and fracture resistance. It also includes a variety of additional ingredients. Corrosion and oxidation-resistant stainless steels normally require an additional % chromium to be added. Steel is widely applied in buildings, tools, ships, railroads, infrastructure, cars, machineries, and weapons due to its high strength and low cost. Aluminum is a chemical compound having a lower density than other common metals. When exposed to air, aluminum has a strong affinity for oxygen and produces a protective layer of oxides on the surface. Aluminum has a silver-like appearance, both in appearance and in its ability to reflect light. It is ductile, soft, and non-magnetic. The advantages of an aluminum profile system start with the material's basic properties. Despite being much lighter than steel, aluminum is a very robust material. Corrosion does not pose a serious threat to it, so no time-consuming preventative actions are necessary. As a result, two traditional steel-related cost issues, such as routine maintenance and corrosion prevention, becomes obsolete. The properties of aluminum and steel are shown in Table 1.

The initial sketching and design of the circular component which is intended to be a wheel is done in the sketcher of fusion 360. Simulations are performed by using an optimum mesh density (3% of the average mesh size). Primarily two conditions are considered for the simulation and only static analysis is performed. The weight of the car for simulation is estimated to be approximately 900 kg (without any passenger) and considering 5 adults with luggage to be approximately 1350 kg (including the passenger's weight). When these masses are converted into weights and equally distributed on to four wheels for static analysis, it results as 2.25 kN and 3.375 kN, respectively. The initial thickness and diameter of the wheels are considered as 53 mm and 432 mm, respectively [9].

4.2 Meshing

Meshing is the act of breaking down an object's continuous geometric space into thousands or more shapes in order to adequately define the object's physical shape. The more intricate a mesh, the more accurate would be the results from the high-fidelity simulations. One of the most important aspects of getting correct results from a FEA model is meshing. To accurately discretize stress gradients, the elements in the mesh must take into consideration a variety of factors. Because the designs are better sampled over the physical domains, the smaller the mesh size, the more accurate the solution.

Finer meshes can provide a more accurate solution, but as a mesh becomes finer, computing time increases, therefore a good balance between accuracy and available computational resources must be struck. The entire process is shown in Fig. 1. Mesh refining is a useful tool for fine-tuning finite element meshes and improving solution accuracy. Refinement is done through an iterative process that involves finding a solution, calculating error estimates, and refining elements in high-error areas and it is much more needed to make sure the mesh size is less than 3% for a finer mesh.

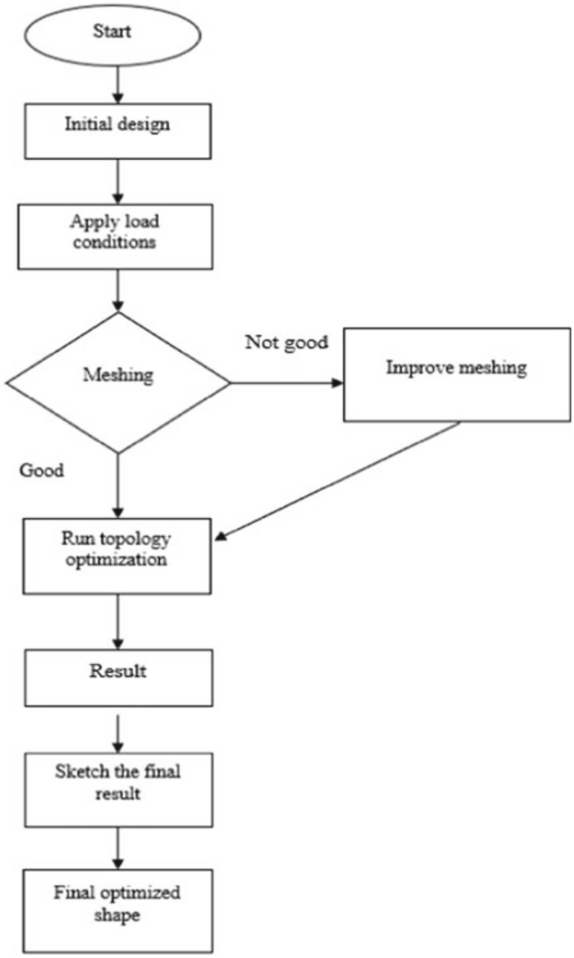
The loading condition for the finite element simulations for the starting models is shown in Fig. 2, while the preliminary result with the optimized design of steel wheel with a load of 2.250 kN is shown in Fig. 3. The results after performing the topology optimization for two different materials and loadings are shown in Table 2.

5 Conclusions and Future Work

Using the approach of topology optimization, entirely different configuration of the wheel designs was obtained when the material and loading conditions were changed. For the steel material, weight reduction of 69–73% was obtained when the load condition was changed from 2.250 to 3.375 kN. However, using aluminum, the mass reduction obtained was between 61 and 71% when the load condition is considered from 2.250 to 3.375 kN.

In the current study, the loads were only applied in static analysis and further work would be done by applying different loads like inertial load, dynamic load and impact load, etc. The materials considered would be altered according to the current industry standards and simulations would be extended to obtain better design than the existing one.

Fig. 1 Flow chart showing the entire procedure for simulation



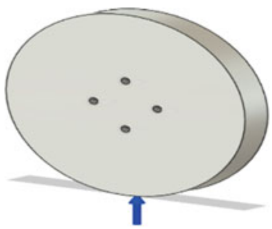


Fig. 2 Load of 2.25 kN applied on steel wheel

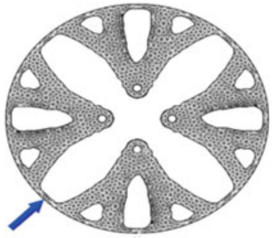


Fig. 3 Final optimized design of steel wheel

Table 2 Optimization designs of wheel with respect to load conditions

S. No.	Material used	Load condition (in kN)	Initial weight (in Kg)	Final weight (in Kg)	Mass reduction (percentages)	Optimum designs obtained
1	Steel	2.250	61.848	16.524	73.28	
		3.375	61.848	18.608	69.13	
2	Aluminum	2.250	20.874	6.330	69.67	
		3.375	20.874	8.090	61.24	

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