Optimization of Brake Pedal

Bhagyashri Kurkure[1], Mr. D. B. Sadaphale[2]

SSBT College of Engineering and Technology, Jalgaon, Maharashtra, India

Abstract : **The modern automotive industries are replacing acceletor and clutch pedal by lightweight materials such as polymer composites, plastic, aluminium and its alloys, etc. The purpose of new design is without change in material reduction weight, cost, and improvement in corrosion resistance.**

This paper is carried out on a commercial vehicle casted brake pedal lever. The finite element modeling and analysis of a brake pedal lever has been carried out. It includes one brake pedal at its actual mounting position in the vehicle. The FE model of the brake pedal assembly has been generated in CATIA or Pro-E and imported in ANSYS for stress analysis and then optimizing it with the help of Optistruct software, which are most popular CAE tools. The FE analysis of the brake pedal lever has been performed by discretization of the model in finite nodes and elements and refining them under defined boundary condition. Bending stress and deflection and reduced weight are the target results. A comparison of both i.e. baseline and optimized model FEA results have been done to conclude.

Keywords: **Optimization, Topology, Stress, FEA.**

I. INTRODUCTION

In recent year, the material competes with each other for existing and new market. Over a period of time many factors that make it possible for one material replace to another for certain application. The main factors affecting the properties of the materials are strength, cost and weight. In automobile industries it is mandatory to look for cheap and lightweight materials and which should be easily accessible. The constituents of a composite are generally arranged so that one or more discontinuous phases are embedded in a continuous phase. The discontinuous phase is termed the reinforcement and the continuous phase is the matrix. A brake pedal in motor vehicles has the task of providing the driver's command through foot leg on master cylinder of the brake system in a vehicle during stopping or reducing speed of a vehicle.

Today the optimization of the product is the vision for reducing the weight and so the cost of the product. The functional stiffness while keeping to comply the best functioning stiffness is the main challenge while reducing the material and the so the cost. In this study we are planning to find the max functional stress locations for the baseline design and then optimizing it using FEA Software and checking the functionality for this optimized design as well.

The aims and scope of the research paper is to reduce the weight of an existing brake pedal design of a car with the application of topology optimization without the substitution of material. By reviewing the design constraints, load and boundary condition the topology optimization was run and the analysis. However the result of optimization process needs for further refinement as it has manufacturability deficiency. Thus knowledge of design engineers to interpret and refine the proposed design is vital to ensure it is possible for production. In conclusion, the application of topology optimization with the integration of engineering knowledge of design engineer able to produce an optimal brake pedal design in a short time.[3],[4]

II. LITERATURE SURVEY

The paper titled "A Conceptual Design of the Concurrent Engineering Design System for polymeric – Based Composite Automotive Pedals" by the author S. M. Sapunan, the abstract is given here. In this study, a study of conceptual design for the polymeric-based composite automotive pedal box system is presented. This study describes the importance of the concurrent engineering technique in the total design activity. Seven idea generation methods like the extension of the search space, the morphological chart, the exploitation of the morphological charts enabled designers to identify the sub-solutions to each sub-functions of the pedal box system. The evaluation matrix method was used to decide on the final concept for the mounting bracket arrangement. The final solution for the polymeric- based composite pedal box system was three pedal mounted onto a common mounting bracket. The clutch and the brake pedals were finally compared and evaluated.

The paper titled "Conceptual Design and Analysis of Brake Pedal Profile", by the authors K.K.Dhande, N.I.Jamadar, SandeepGhatge the abstract is given here. The modern automotive industries are replacing acceletor and clutch pedal by lightweight materials such as polymer composites, plastic, aluminium and its alloys, etc. The purpose of replacement is reduction weight, cost, and improvement in corrosion resistance. In aviation; the steel material is replaced by light materials. In this study various lightweight materials are compared with conventional steel for brake pedal. These materials are analysed for different sections for different loading and boundary conditions. The aim of this study is to design and analyse the brake pedal using CATIA and ANSYS software

The paper titled "Topology Optimization in Automotive Brake Pedal Redesign", by the authors Mohd Nizam Sudin, Musthafah Mohd Tahir, Faiz Redza Ramli, Shamsul Anuar Shamsuddin,the abstract is given here. Nowadays, automotive industry is continuing to strive for light weight vehicle in improving fuel efficiency and emissions reduction. To produce a better performance car it is important to design vehicles with optimum weight. In order to reduce the weight of vehicle without sacrificing its integrity, this project aims to employ topology optimization technique to propose an optimal design of an automotive component in early phase of product development. In this project the material used for an existing brake pedal is unchanged as this study focuses on reducing weight of existing brake pedal without material substitution. The digital model of an existing brake pedal was generated using CATIA V5 solid modelling software. Topology optimization was performed by using Altair Optistruct software under linear static stress analysis. Finally, a new light weight design brake pedal is proposed. The result of the study shows that the weight of a new designed brake pedal was 22% less as compared to an existing brake pedal without sacrificing its performance requirement.

The paper titled "Design and Analysis of Composite Brake Pedal: An Ergonomic Approach" by the authors K KDhande, N I Jamadar, Sandeep Ghatge the abstract is given here In recent years, the conventional brake, accelerator and clutch pedals of automotive vehicles are replaced by polymeric-based composite pedals. The purpose of replacement from metallic pedal to polymeric-based composite material is to reduce the weight, cost and improve material degradation by corrosion. In this paper four different sections of polymeric based brake pedals are analysed as per the design parameters received from General motors. The sections are analysed and arrived at a winning concept based on stiffness comparison. A full scale model is developed from the winning concept, while developing full scale model an ergonomic study has been made on few hatch back and SUVs car's to improve the driver's comfort and reduce fatigue due to breaking operation. The pedal is modelled using CATIA software and analysis is carried out in ANSYS software. The results have shown polymeric-based composite material meets the requirements of manufacturer's specification and can be replaced with present metallic pedal. Weight reduction of 66.7% is achieved by using composite material.

2.1 Criteria for new design and optimization of brake pedal:

The modern automotive industries are replacing acceletor and clutch pedal by lightweight materials such as polymer composites, plastic, aluminium and its alloys, etc. The purpose of replacement is reduction weight, cost, and improvement in corrosion resistance. In aviation; the steel material is replaced by light materials. The information gathered in literature review is processed and the salient findings and shortcomings are illustrated. Considering this aspect, how the problem of the present work to find out the max stress area due to working loads and optimization for weight reduction using CAE is explained. The literature review has enunciated the criteria of Stress analysis and optimization of brake pedal techniques available.

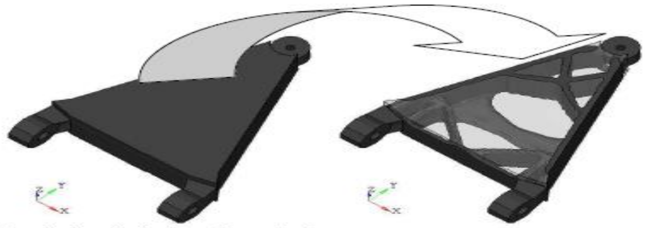
III. STRUCTURAL DESIGN AND OPTIMIZATION

Structural design tools include topology, topography and free sizing optimization. For structural optimization sizing, shape and free shape optimization are available.

In the formulation of design and optimization problems the following responses can be applied as objective or constraints: Compliance, frequency, volume, mass, moments of inertia, center of gravity, displacements, velocities, accelerations, buckling factor, stresses, strains, composite failure, forces, synthetic responses, and external (user defined) functions.

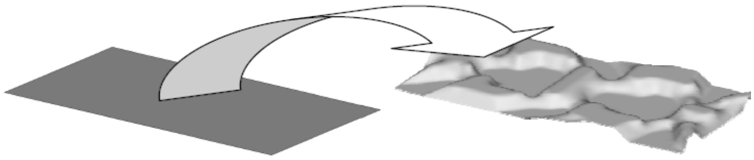
Static, inertia relief, non-linear gap, normal modes, buckling, frequency response solutions can be included in a multi-disciplinary optimization setup.

Topology: is a mathematical technique that optimized the material distribution for a structure within a given package space



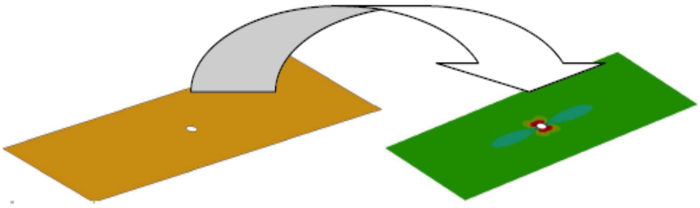
Topologic optimization of a control arm

Topography: Topography optimization is an advanced form of shape optimization in which a design region for a given part is defined and a pattern of shape variable-based reinforcements within that region is generated using Optistruct.



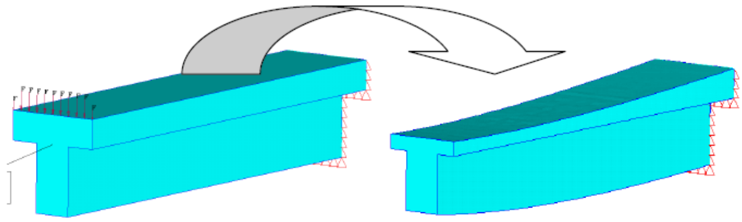
Topographic optimization of a plate

Free Size: is a mathematical technique that produces an optimized thickness distribution per element for a 2D structure.



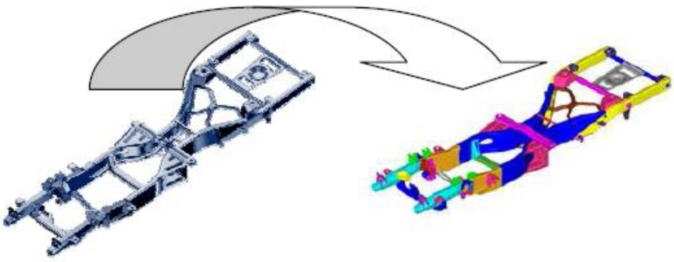
Free-size optimization (Laminate total thickness)

Shape: is an automated way to modify the structure shape based on predefined shape variables to find the optimal shape.



Cantilever beam Shape optimization

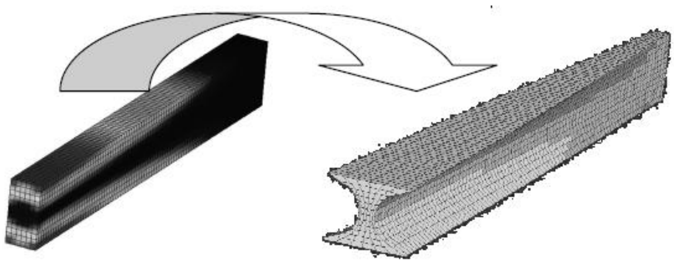
Size: is an automated way to modify the structure parameters (Thickness, 1D properties, material properties, etc…) to find the optimal design.



Size optimization (shell thickness and material properties)

Gauge: is a particular case of size, where the DV are 2D props (Pshell or Pcomp)

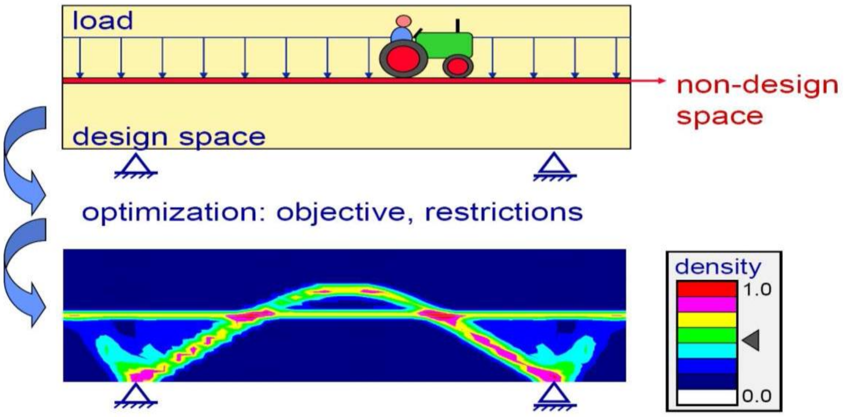
Free Shape: is an automated way to modify the structure shape based on set of nodes that can move totally free on the boundary to find the optimal shape.



Free-shape optimization result for a cantilever beam

IV. TOPOLOGY OPTIMIZATION

Topology Optimization is a mathematical technique that produces an optimized shape and material distribution for a structure within a given package space. By discretizing the domain into a finite element mesh, OptiStruct calculates material properties for each element. The OptiStruct algorithm alters the material distribution to optimize the user-defined objective under given constraints.



Example of a topology optimization OptiStruct solves topological optimization problems using either the homogenization or density method. Under topology optimization, the material density of each element should take a value of either 0 or 1, defining the element as being either void or solid, respectively.

Unfortunately, optimization of a large number of discrete variables is computationally prohibitive. Therefore, representation of the material distribution problem in terms of continuous variables has to be used.

Steps of the optimization Methodology:

1. Design Verification of the baseline assembly for design targets.
2. Optimization of the brake lever assembly for reducing the weight. And result interpretation.
3. Changing the baseline design according to the optimization result suggestions.
4. Design verification of the new optimized design.
5. Comparing the results for baseline and optimized model.

V. TOPOLOGY OPTIMIZATION IN NEW BRAKE PEDAL DESIGN

Topology optimization technic will be used for reducing the volume of the brake lever assembly.

The following Parameters will be used for the Topology Optimization:

1. Design Variable: will be the Brake Lever Property

2. Responses: a. Volume Fraction: Upper limit will be 30% of the baseline design.

b. Static Compliance: compliance should be there for the static loadcase.

3. Constraint: Volume Fraction should be max 30%.

4. Objective: Min Compliance.

Traditionally, brake pedal is often designed by iterative methods, optimized under non-optimal topologies and often based on static loading conditions. The following optimization stages were carried out to obtain the optimal layout of material in new brake pedal design.

A. Stage 1: Define the Initial Design Space and FE Model:

To begin the topology optimization process the amount of volume that the geometry can safely occupy that is known as the design space was determined. It represents the volume that will be meshed into finite elements and iterated upon while the optimization algorithm is working. In addition any space that needs clearance for being iterated during the optimization was determined as non-design space so that the software does not try to use that space for load-bearing elements. In the case of brake pedal the hole for the pivot shaft and brake pedal pad were set as non-design space and represented in orange colour in Figure 1.

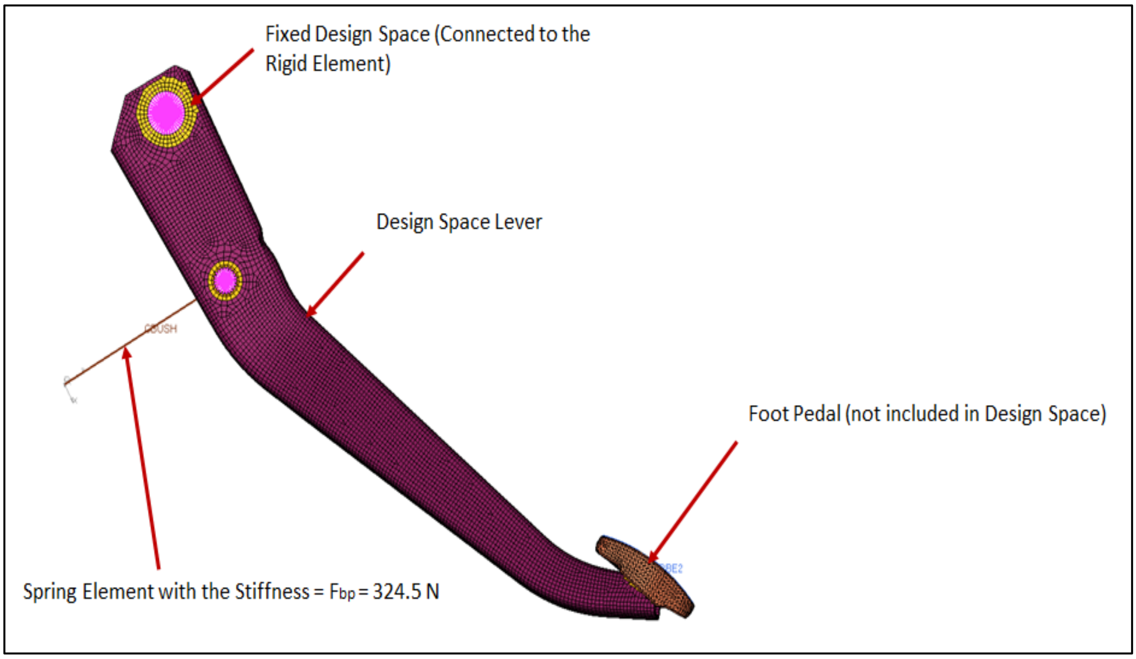


Fig.1 Baseline Model of Brake Pedal Assembly

The design in space previously created in a CAD program was imported as an IGES (Initial Graphics Exchange Specification) file and the geometry was "cleaned" to prepare for meshing. This means that some of the lines in the imported model were toggled from edge lines to suppressed (or manifold) lines so that they would not represent an artificial edge. Once the geometry was cleaned, the design space volume was filled with tetrahedral elements using the auto-mesh features of HyperMesh. The mesh quality was acceptable as only 6% errors were found. Youngs's modulus (E), Poission's ratio (ν) and density (ρ) for the steel material of brake pedal is taken as 2.1 x 10^5 MPa, 0.3 and 7.9 × 10^2 kg/m^3, respectively and classify as isotropic. The load applied on the brake pedal pad was a normal 1000 N force with maximum allowable displacement is 10mm and Spring Element with the Stiffness is Fbp = 324.5 N.Figure3 Stress Contour Plots for Baseline Design, it depicts Max Stress 291.728 Mpa and Yield Stress is 340 MPa[1],[2].

B. Stage 2: Topology Optimization:

The current design of the pedals is overdesigned. As it is showing the max displacement is 2.225 mm when the allowed limit is 10 mm. This is 22.25 % higher than the design target.Baseline Wt. is 0.82 Kg. So there is a vast scope of Optimization is available.The objective function of any optimization problem is to minimize or maximize a certain response while meeting a prescribed set of constraints. For this it is necessary to program the software to solve for the

International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 3, Issue 1, pp: (175-183), Month: April 2015 - September 2015, Available at: www.researchpublish.com

desired responses, and then choose limits to these responses. In the case of the brake pedal optimization, the set objective function was to minimize the mass while maintaining its integrity. Obviously the mass minimization cannot be continued without limit, thus it is necessary to define responses that have upper and/or lower limits as constraints. For the design of brake pedal the stress must be below the material yield stress as to obtain minimum safety factor 1.5. In addition the maximum displacement is 10 mm.

The topological optimization procedure consists of following main steps:

Step 1: define optimization functions

Step 2: define objective and constraints

Step 3: initialize the optimization parameters

Step 4: execute the topological optimization

Step 5: review the results.

In this case study, the density of each element is selected as the design variable and above given steps is carried out using Optistruct software. A finite element model of topology after material removed from brake pedal is given in Figure 6.

C. Stage 3: Material Removal Process:

The optimization process took 50 iterations to remove the unwanted material from the design space. After removing the Suggested material from the baseline design as per Optimization Process, the New Design wt is 0.67 Kg . So the wt reduced is 18.29%.Although the topology result appears reasonable, obviously the design is definitely not ready for production. Thus the result of topology optimization was redefined based on material distribution as in Figures 6. Some interpretation was required to create the final design. The geometry was opened in a CAD environment as the Optistruct has the ability to export the topology results as IGES file using an export future. The optimize shape after interpretation was created using CATIA V5 software is shown in Figure 7. There are some considerations in interpretation step or the engineering knowledge that was considered to interpret new design from topology results. For example, appropriately sized fillets were utilized to reduce stress concentrations and to aid manufacturability using standard tooling. The design retains the feature proposed by OptiStruct such as the holes in the pedal arm and retains the material between the pedal arms to the pedal pad.

VI. RESULTS AND DISCUSSION

To validate the structural integrity of the newly designed brake pedal, a finite element analysis was performed as to ensure that the design did not have any inherent stress concentrations or fatal flaws. The boundary conditions, load case and mesh parameters were the same as used in the optimization analysis. Figure 8 and Figure 9 shows the displacement plot and Stress distribution for the optimized design. From the finite element results of Figure 9 there does not appear to be any severe stress concentrations that would indicate a faulty design as the highest stress levels is Max Stress = 314.49 Mpa meanwhile the material Tensile Strength is 550 MPa, that give safety factor roughly 1.5. In addition, the percentage of weight reduction is approximately 18.29 %.

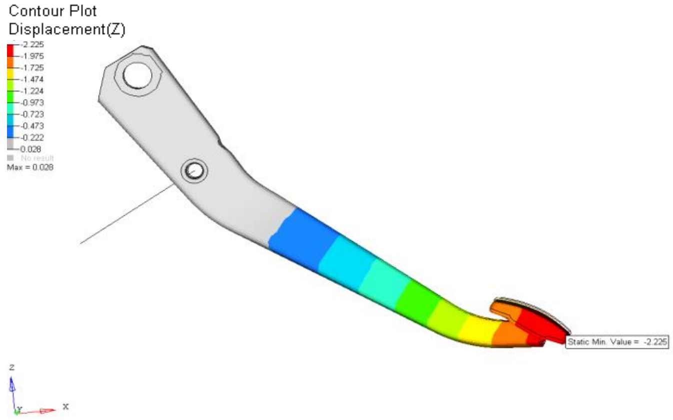
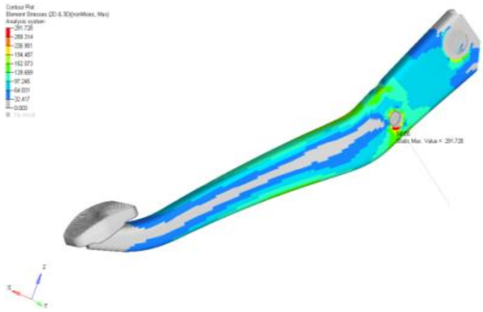


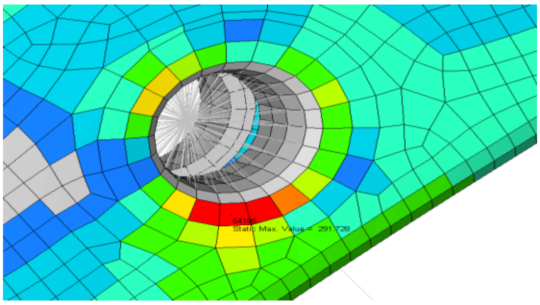
Fig 2.Displacement Contour Plotfor Baseline Design (Max Displacement = 2.225 mm)

International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 3, Issue 1, pp: (175-183), Month: April 2015 - September 2015, Available at: www.researchpublish.com



(a)

Fig 3.Stress Contour Plots for Baseline Design



(b)

Fig 4.Brake Force Output for Baseline Design

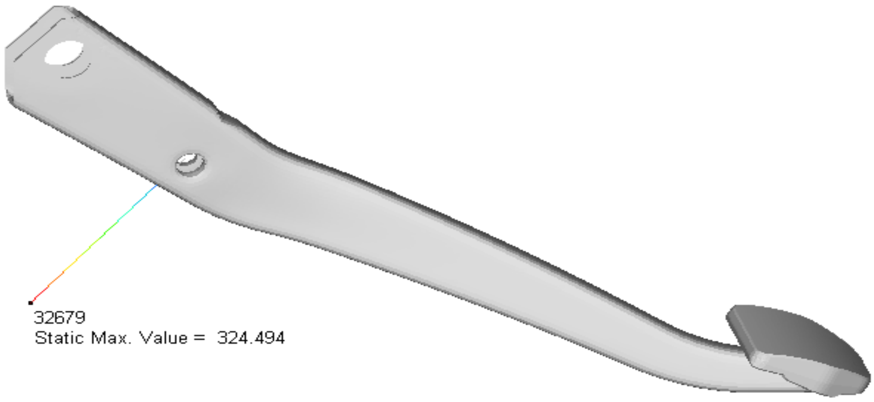


Fig 5

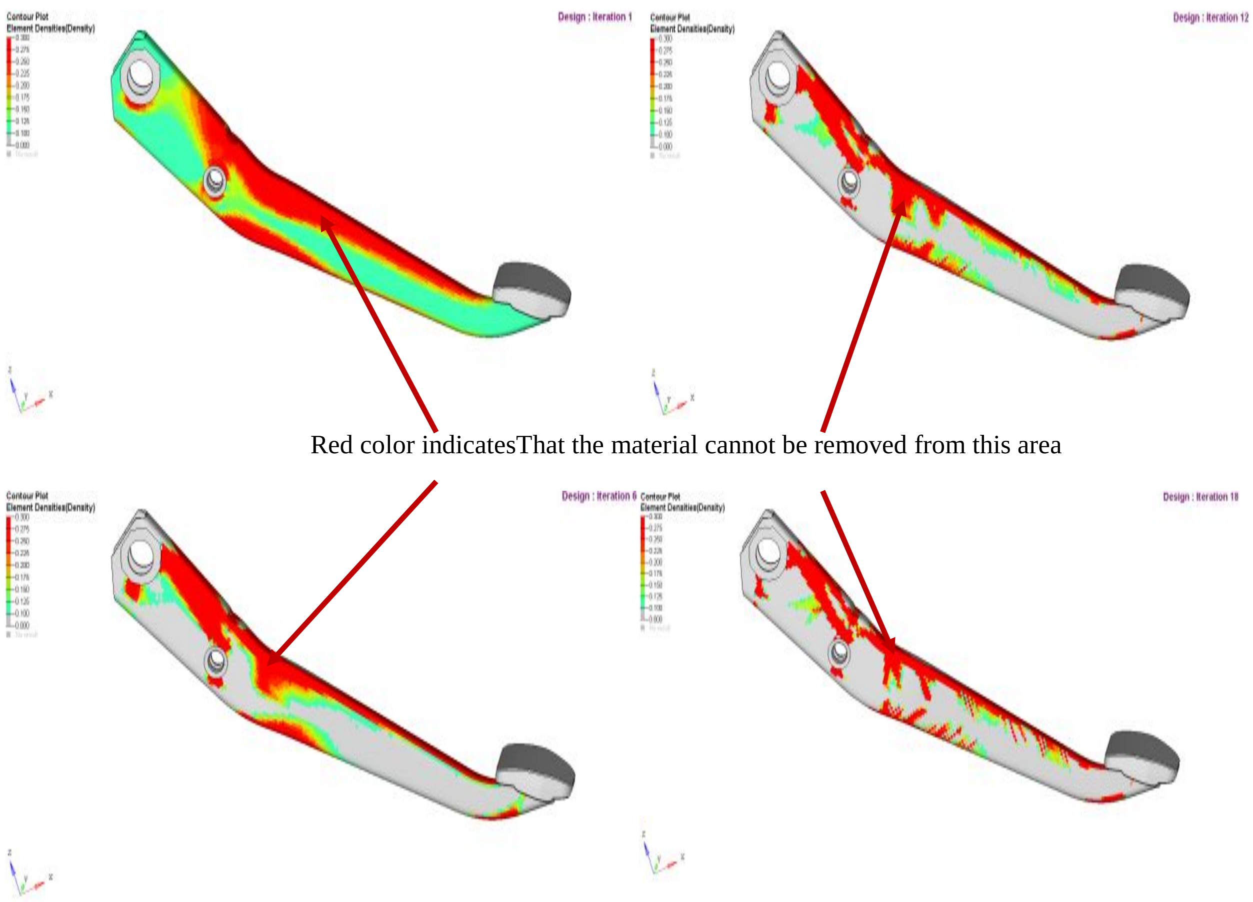


Figure 6.Topology Optimization Suggestions

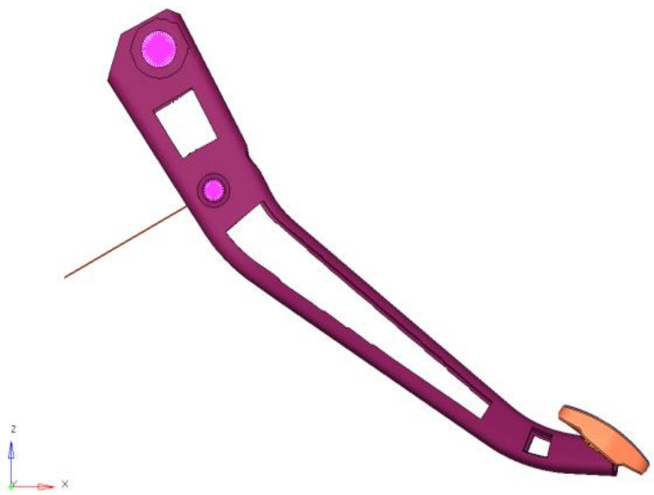


Fig 7.Optimized Modelof Brake Pedal Assembly

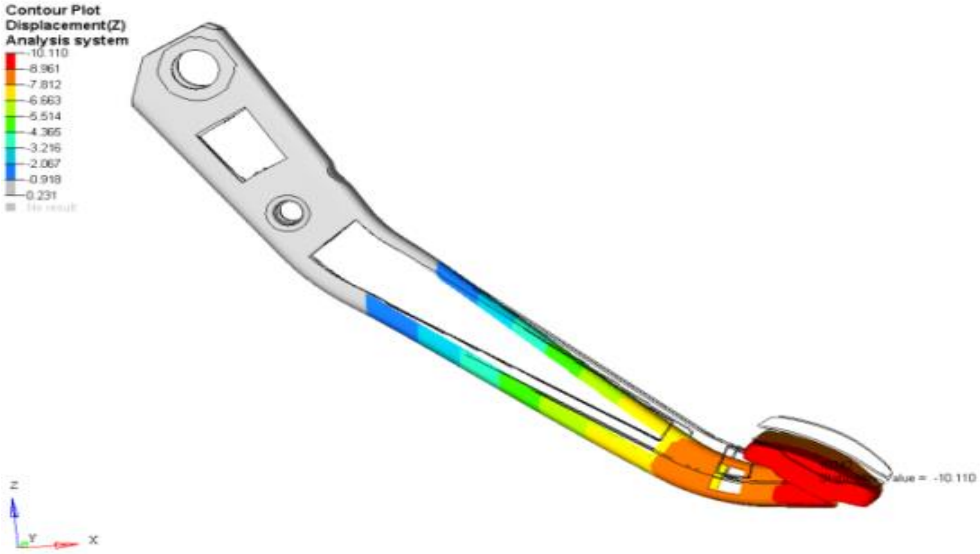
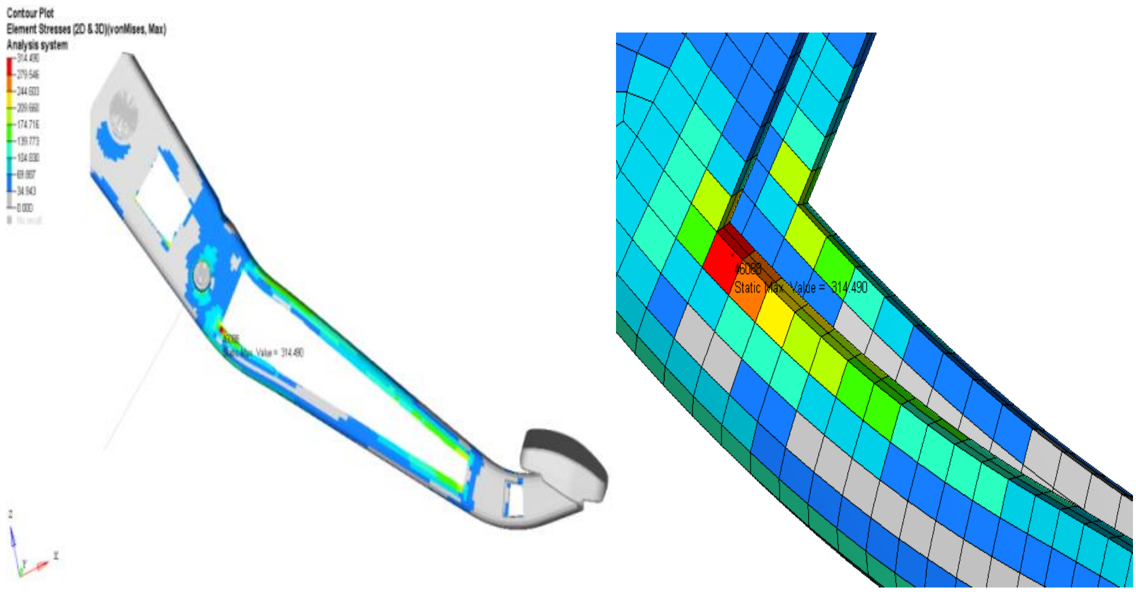


Fig 8.Displacement Contour Plots for Baseline Design (Max Displacement = 10.11 mm)



(a) **(b)**

Fig 9.Stress Contour Plots for Optimized Design

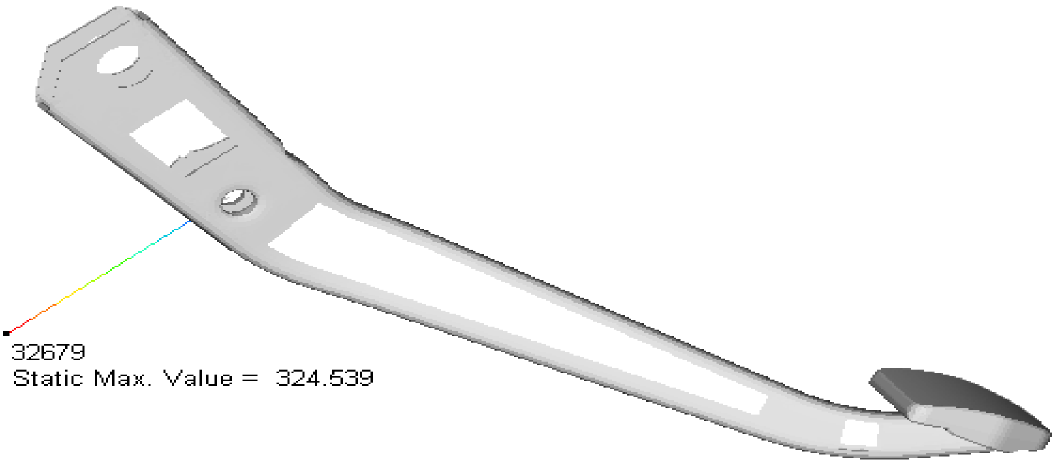


Fig 10.Brake Force Output for Optimized Design

VII. CONCLUSIONS

Brake lever is the predominant component of the automobiles, so need to analyze the static structural behavior. In this regards, modeled one design of brake and carried out simulation in Optistruct Solver for total deformation considering materials like structural steel. The baseline design shows the max displacement of 2.225 mm. Which shows there is design space for optimization as the target displacement value is 10 mm. Optimization run has been completed for getting the idea from which point material can be removed.So removed the material from the baseline model as per the optimization results.Reanalyze the new design which shows all the wt. reduction of 18.29 % as well as Volume Reduction of 18.82 % and stress levels are within the yield limit as well as meeting the functional requirements.So we can conclude that the Design has been Optimized using topology Optimization Process.In conclusion, the application of topology optimization with the integration of engineering knowledge of design engineer able to produce an optimal brake pedal design in a short time.

REFERENCES

[1] S. M. Sapunan, "A Conceptual Design of the Concurrent Engineering Design System for polymeric – Based Composite Automotive Pedals", American Journol of Applied Science 2 (2): 514-525, 2005, ISSN 1546-9239.

[2] K.K. Dhande, N.I. Jamadar, Sandeep Ghatge, "Conceptual Design and Analysis of Brake Pedal Profile", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 11, November 2014, pp. 17432 – 17441

[3] Mohd Nizam Sudin, Mustha fah MohdT ahir, Faiz Redza Ramli, Shamsul Anuar Shamsuddin,"Topology Optimization in Automotive Brake Pedal Redesign", International Journol of Engineering and Technology (IJET), ISSN 0975-4024 Vol 6 No 1 Feb- Mar 2014, pp 398 – 402.

[4] K KDhande, N I Jamadar, SandeepGhatge, "Design and Analysis of Composite Brake Pedal: An Ergonomic Approach", ISSN 2278 – 0149, IJMERR, Vol. 3, No. 3, July 2014

[5] N. Muthukrishnan, J. Paulo Davim "Optimization of machining parameters of Al/SiC-MMC". Journal of materials processing technology 209 (2009) 225–232