

Topological Optimization of Linear Elastic Structures Using Optimal Criterion Approach

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ABSTRACT

Topological optimization may be defined as the process of obtaining the best possible results among many possible results under given circumstances. The topology optimization deals with finding the optimal material distribution in a design domain while minimizing the compliance of the structure. In this paper, a software based approach for topology optimization of three benchmarked plane stress models structures is presented through a commercially available finite element software ANSYS. The results of the ANSYS based Optimality criterion are validated and compared with the results obtained by Level Set method. ANSYS makes use of topology optimization with the help of the Solid Isotropic Material with Penalization (SIMP) scheme for the penalization of the intermediate design variables.

Keywords: Optimization, SIMP, Topology.

1. INTRODUCTION

Design optimization is a subject which has captured the minds of researchers for many years. During recent decades research on this area has provided methods for design parameterization, automated finite element mesh generation and mathematical programming. The only known quantities in the problem are the applied loads, the possible support conditions, the volume of the structure to be constructed and possibly some additional design restrictions such as the location and size of prescribed holes or solid areas. In general, the optimization of an objective function (cost/weight) is basically the maximization or minimization of a problem subjected to constraints (Stress, deflection etc.). In an optimization problem, various solutions are compared and contrasted with each other and the best result is sought. In this paper, a software based approach for topology optimization of three benchmarked plane stress models structures is presented through a commercially available finite element software ANSYS. The results of the ANSYS based Optimality criterion are validated and compared with the results obtained by Level Set method.

1.1 Solid Isotropic Material with Penalization Approach (SIMP):

The SIMP method is the basis for the design parameterization in topology optimization. The goal is to create regions of uniform material distribution to minimize a specific structural property (e.g. compliance). In this method, a discretized (e.g., finite element) model of the structural domain as shown in figure 1 is used to perform the structural analysis and optimization.

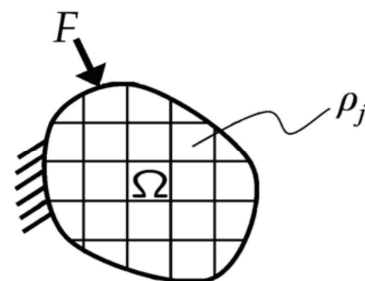


Fig..1: Discretized model of the structural domain

2. MATERIAL AND METHODS

By treating the non-dimensional density of each element as an independent design variable and relating the other physical

and engineering properties to element density, a parameterized model is developed that can be used to find such properties as stiffness, thermal conductivity, magnetic permeability, porosity, etc. Theoretically, the non-dimensional density takes a value of one or zero for a solid or void element, respectively. The stiffness of any element is related to the material stiffness by a power-law. Using this power law, the intermediate relative densities are penalized. This penalization evolves a solid-void topology.

2.1 Selection of Element Types and Meshing

The element which ANSYS supports for topology optimization is Plane 82. Plane82 is an 8-node element with 4 nodes at each corner of the quadrilateral and 4 nodes at centers of the edges of quadrilateral as shown in figure 2. Each node has 2 degrees of freedom. Plane82 elements have excellent properties for most of the applications. They have quadratic shape functions.

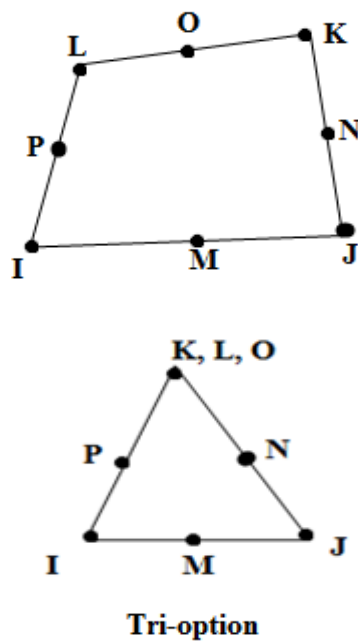


Fig 2: Plane82 element with quad and tri-options

2.2 Specimen Geometries Used

In the present investigation, three specimen geometries and boundary conditions applied have been used as shown in figures 3 to 5. The specimens are taken from the work of **Qi Xia et al. [2012]**.

Each of the five models are characterized by the finite element discretization in $x(n_x)$ and $y(n_y)$ directions and the volume

usage fraction (V_0) used. The material properties and loads used are given in table 1.

Table 1: Material Properties and load used

Young's Modulus (E) ($\frac{N}{mm^2}$)	Poisson's ratio (ν)	Load (N)
1	0.3	1

(a) Model 1

This case comprises of a L-shaped beam with a unit vertical concentrated load $t=1$ N applied at the middle point of the right side. The beam here is being optimized for minimum compliance. The beam is fixed at the top. The volume fraction usage is 50%. The beam is under a state of plane stress. The complete model is shown in figure 3.

(b) Model 2

Here a L-shaped beam with a unit vertical concentrated load $t=1$ N applied at the tip of the right side of the beam. The beam is under a state of plane stress and is supported at the top by a fixed support. The beam is under a state of plane stress and volume fraction usage is 50%. The complete model is shown in figure 4.

(c) Model 3

A Michell structure having dimensions $2\text{mm} \times 1\text{mm}$ is considered in this case. A unit vertical load $t=1\text{N}$ is applied at the middle point of the bottom side. A volume usage fraction of 30% is used here.

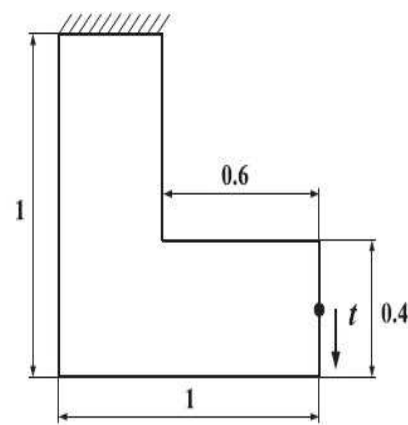


Fig-3.: Geometry and boundary conditions for Model 1

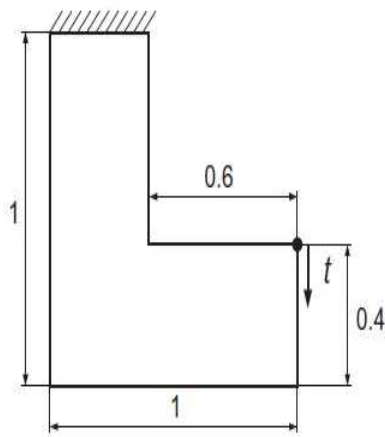


Fig-4: Geometry and boundary conditions for Model 2

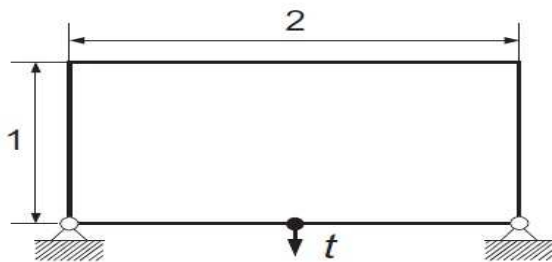


Fig-5: Geometry and boundary conditions for Model 3

3. RESULT AND DISCUSSIONS

The final compliance and optimal shape of the models obtained with the help of gradient based ANSYS based Optimality Criterion have been compared with a level set method. Here the work is described step by step from the definition of the problems to the analysis of the resulting design and evaluation of the used method. Description of the model in X and Y directions is done with 8-node triangular and quadrilateral elements. For each model material properties, volume fraction usage, convergence criterion and meshing conditions has been described.

Each of the three models are characterized by the finite element discretization in $x(n_x)$ and $y(n_y)$ directions and the volume usage fraction (V_o) used.

For model 1, Table 2 shows the final compliance obtained in the case of ANSYS based OC and level set method.

Table 2: Comparison between OC and Level Set for model 1

Method	Compliance	Von-mises stress	Iteration
ANSYS based OC	167.94	85.675	36
Level set method	175	86	800
Percentage difference	4.03	.377	

The optimal topologies obtained with ANSYS based OC and level set method are shown in the figure 6 for an edge element length of 0.025.

Initial compliance obtained in the first iteration is 423.80 Nmm, which drops to 324.48 Nmm in second iteration and 234.49Nmm in the third iteration. The final compliance obtained with the help of ANSYS based OC is 167.94Nmm after 36 iterations. On the other hand, the level set method gives a final compliance of 175 after 800 iterations. The optimal criterion based on ANSYS reaches a more optimal solution after less number of iterations.

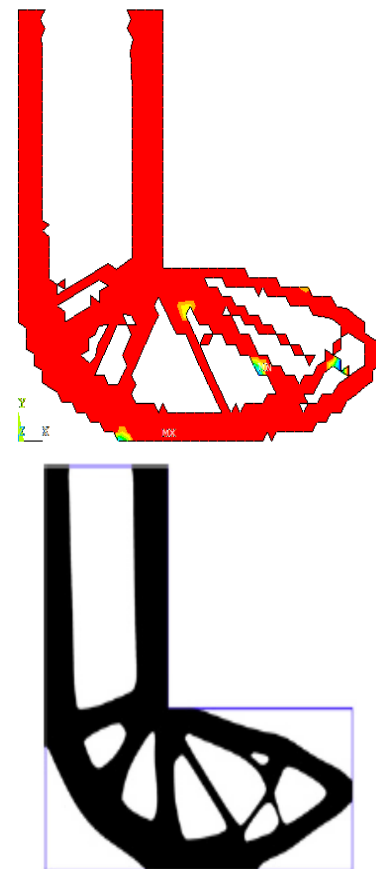


Fig-6: Optimal shapes obtained by (a) ANSYS based OC and (b) Level Set Method

For model 2, Table 3 shows the final compliance obtained in the case of ANSYS based OC and level set method.

The optimal topologies obtained with ANSYS based OC and level set method are shown in the figure 7 below for a edge element length of 0.025

Table 3: Comparison between OC and Level Set for model 2

Method	Compliance	Von-mises stress	Iteration
ANSYS based OC	173.67	86.13	32
Level set method	190	87	800
Percentage difference	8.594	1	

Initial compliance obtained in the first iteration is 441.69Nmm, which drops to 326.95Nmm in second iteration and 239.63Nmm in the third iteration. The final compliance obtained with the help of ANSYS based OC is 173.67Nmm after 32 iterations. On the other hand, the level set method gives a final compliance of 190 after 800 iterations. The optimal criterion based on ANSYS reaches a more optimal solution after less number of iterations.

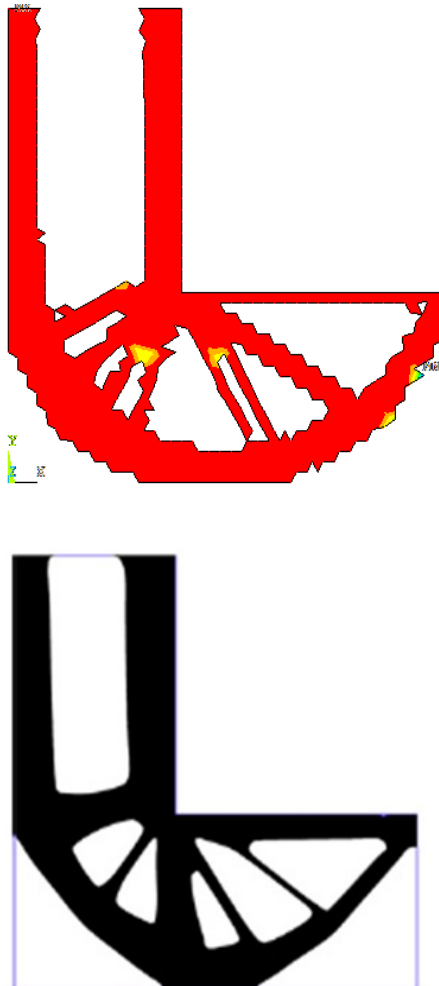


Fig.-7: Optimal shapes obtained by (a) ANSYS based OC and (b) Level Set Method

For model 3, a Michell structure having dimensions 2mmX1mm is considered. Table 4 shows the final compliance obtained with ANSYS based OC and level set method for a

edge element length of 0.025 and a volume usage fraction of 30%.

Table 4: Comparison between OC and Level Set for model 3

Method	Compliance	Von-mises stress	Iteration
ANSYS based OC	13.509	11.905	34
Level set method	18	9	300
Percentage difference	24.95	24.401	

The optimal topologies obtained with ANSYS based OC and level set method are shown in the figure 8 for a edge element length of 0.025.

Initial compliance obtained in the first iteration is 75.801, which drops to 47.304 Nmm in second iteration and 32.861 Nmm in the third iteration. The final compliance obtained with the help of ANSYS based OC is 13.509 Nmm after 34 iterations. On the other hand, the level set method gives a final compliance of 18 after 300 iterations. The optimal criterion based on ANSYS reaches a more optimal solution after less number of iterations.

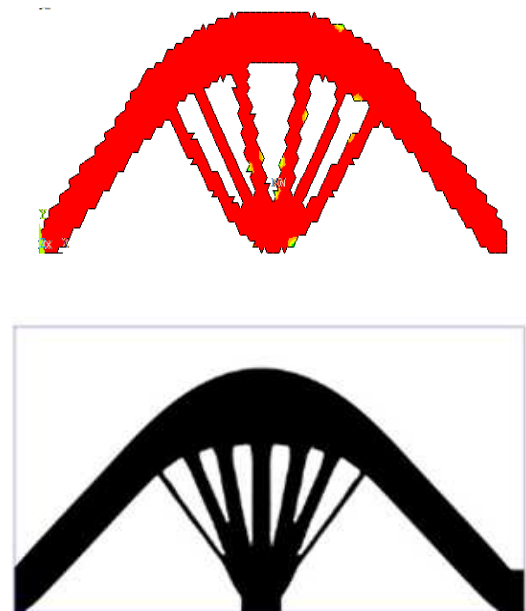


Fig-8: Optimal shapes obtained by (a) ANSYS based OC and (b) Level Set Method

VON MISES STRESS

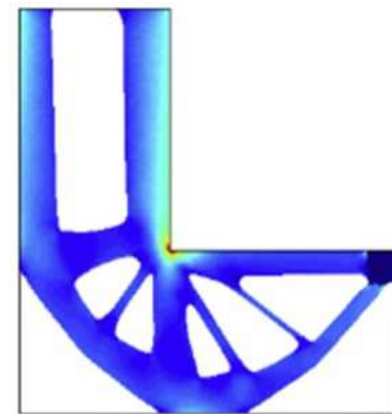
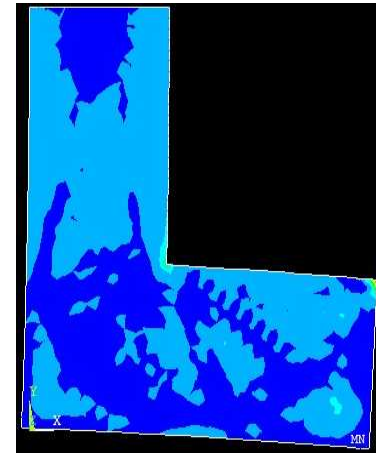
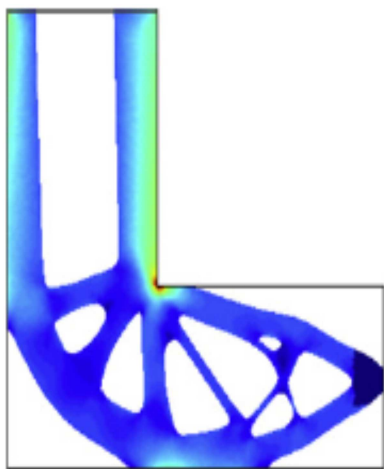
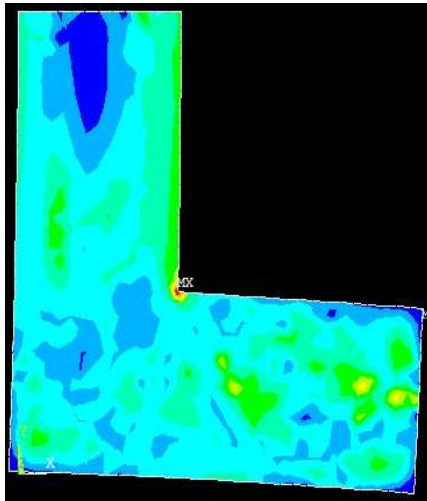


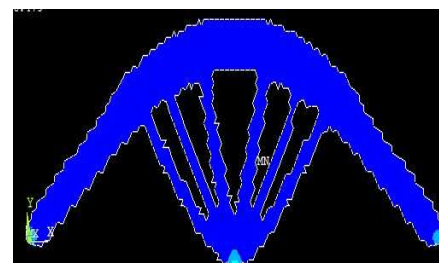
Fig-10: VonMises stresses obtained by (a)ANSYS based OC & (b) Level Set Method for L2

Fig 9: VonMises stresses obtained by (a)ANSYS based OC & (b) Level Set Method for L1

There is a stress concentration at the inner corner of the compliance design. Therefore stresses are calculated at the inner corner of the L-shaped models together with the Michell structure. For L1 the vonmises stress calculated is 85.675 obtained through ANSYS based OC while through the level set method the vonmises stress obtained is 86 . The percentage difference in between the values of the von mises stresses is .377%. The vonmises stresses are shown in the figure 9.

For L2 the vonmises stress calculated is 86.13 obtained through ANSYS based OC while through the level set method the vonmises stress obtained is 87. The percentage difference in between the values of the von mises stresses is 1%. The vonmises stresses are shown in the figure 10.

For Michell structure the vonmises stress calculated is 11.905 obtained through ANSYS based OC while through the level set method the vonmises stress obtained is 9. The percentage difference in between the values of the von mises stresses is 24.401%. The vonmises stresses are shown in the figure 11.



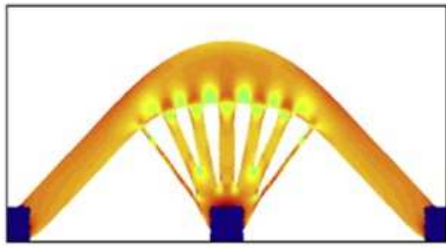


Fig-11: VonMises stresses obtained by (a) ANSYS based OC & (b) Level Set Method for Michell

4. CONCLUSIONS

In this paper, we presented a optimal criterion solution to the stress based topology optimization. Application of the method is demonstrated by several numerical examples of 2D structures. As we can see, the peak stress can be effectively controlled during the optimization and the convergence of the optimization is smooth.

Comparison and validation proves that the optimality criterion method is not giving results that are sub-optimal. Compliance values obtained by ANSYS based Optimality Criterion are lower by **8 to 24.95 %** than the level set method used by **Qi Xia et al. [2012]**. This paper draws attention to the fact that the topology optimization is a very significant and the reasonably toughest element of the design optimization studies. Hence, there appears a call for of studying topology optimization independently. No sum of sizing and shaping optimization can fix mistakes committed in finding optimal distribution of material in the design sphere (topology optimization).

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