# Topology Optimization using Strain Energy based Additive Algorithm & Principal Stress Line based Approach

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## 1. INTRODUCTION & OBJECTIVE

### Abstract

The goal of topology optimization is to find the optimal distribution of the material to satisfy the required boundary conditions and achieve the performance objective. This research work proposes a modified evolutionary algorithm for structural optimization with consideration to strain energy distribution. Addition of material is performed on a partially void space instead of material removal. As the final optimum structure bears only a fraction of initial structure, material addition approach is superior to the material removal approach. The proposed method initially takes a void input design domain but to make numerical computation easy negligible density is assumed. It is a well-known fact that principal stress planes are the strongest planes in structure. By using this principle, a method of topology optimization based on principal stress lines (PSL) is proposed. This method traces the principal planes to find the optimum topology It is observed that with the same volume, strain energy based optimum structure can carry more load than PSL based optimum structure with maximum deformation of 1mm in the whole domain. The result was verified using ANSYS static structure simulation & optimum structure satisfied all the constraints. 3-D printed prototype of the optimum structure was tested in the laboratory with given loading and boundary condition and the result satisfied the constraint of 1 mm deformation.

Keywords: Evolutionary structural optimization (ESO), Bidirectional Evolutionary Structural optimization (BESO), Principal stress line (PSL), Topology Growth, Filtering and Regularization.

### Literature Review

Structural optimization is a technique which can save material by changing the shape, boundary and topology of structure in an optimal way. Majority of the topology optimization methods such as SIMP [1], ESO [2], Level set, etc.is based on material removal process from the initial structure through finite element analysis. Elements which are inefficient and contributes less to the objective function are removed [3]. Additive method of TO was first introduced by O.M. Querin in 2000 which was stress based evolutionary structural optimization method and is much superior to subtractive approach because both computational cost and time taken for the simulation are less for the former [4]. PSL based Topology Optimization (PSLBTO) is a recent method of getting an optimum structure by adding the truss members along the principal stress lines. If this structure is not able to take load, then a topology growth approach is employed. This process of topology growth is continued until we get a structure which takes the load efficiently and satisfies the constraint [5].

## 2.RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

In the present work, six case studies were considered. Case 1: optimum solution from both methods,

case 2: optimum solution for different boundary conditions, case 3: effect of filtering and regularization, case 4: optimum solution for different load, case 5: effect of elements addition and case 6: time comparison of both methods. The corresponding figures are show in figures 2.1 and 2.2

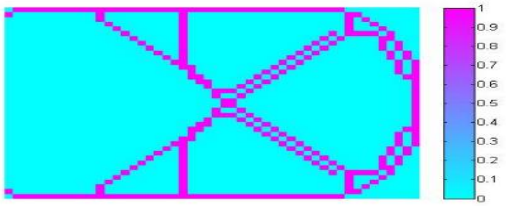

Figure 2.1: Optimum Structure using strain energy based additive algorithm for TO

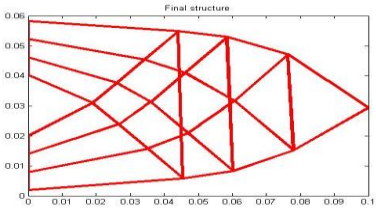


Figure 2.2: TO using PSL Approach

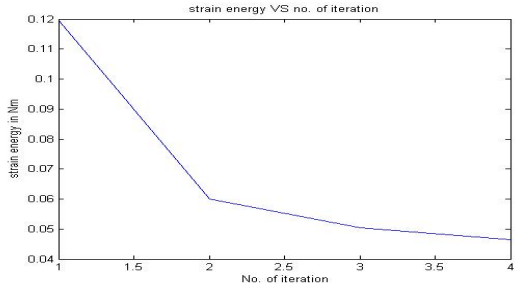


Fig 2.3 Shows SE variation for PSL approach

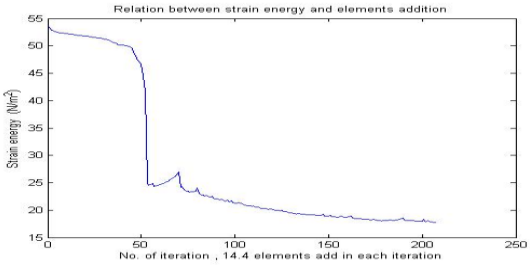


Fig 2.4 Shows SE variation for Additive approach

Table 2.1 compares the result of Strain energy and PSL based TO approach.

| | Strain Energy Based Additive algorithm | | PSL based TO Approach | |
|---|---|---|---|---|
| Parameter | MATLAB | ANSYS | MATLAB | ANSYS |
| Volume | 1.5e4 $mm^3$ | 1.6e4 $mm^3$ | 1.6e4 mm3 | 1.6e4 mm3 |
| Max deformation | 1.1002 mm | 0.953 mm | 1.1002 mm | 0.953 mm |
| Max Stress | 23.9MPa | 23.9 MPa | 23.9MPa | 23.9 MPa |
| Force P | 5 kg | 5 kg | 10 kg | 10 kg |

From the first case study we concluded that with the same volume, the PSL based approach carries more load than strain energy based additive algorithms. From table 2.1 both optimum structures had the same volume of 1.6e4 $mm^3$ and an initial volume of 6e4 $mm^3$. So optimum structure has only 26.667% of the initial volume and also satisfied the constraint of 1mm maximum deflection. An additive algorithm based optimum structure carried only 5 kg of load with 1mm deformation but PSL based optimum structure carried 10 kg of load with 1 mm deformation. Both the above-mentioned methods can be extended for 3-D structure.

## REFERENCES


1. Gersborg-Hansen A, Bendsøe MP, Sigmund O. Topology optimization of heat conduction problems using the finite volume method. Structural and Multidisciplinary Optimization 2006; 31: 251–259.
2. Teimouri M, Asgari M. Multi-objective BESO topology optimization for stiffness and frequency of continuum structures. Structural Engineering and Mechanics 2019; 72: 181–190.
3. Bourdin B. Filters in topology optimization. 2001.
4. Querin OM, Steven GP, Xie YM. Evolutionary structural optimization using an additive algorithm. 2000.
5. Kwok TH, Li Y, Chen Y. A structural topology design method based on principal stress line. CAD Computer Aided Design 2016; 80: 19–31.