Manufacturing Constraints in Topology Optimization Framework

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1 INTRODUCTION

STructural Topology Optimization is a particular method that aims ar optimizing the distribution of material in any specific design domain for given set of loads, constraints such that certain properties like compliance, stress bearing ability are optimized. Topology Optimization is widely used in industries and in any real worls problems where the structure has to be optimized. The several methods are implemented in the whole world of topology optimization.

The most famous approach is the Solid Isotropic Material with Penalization (SIMP) [1,3]. This method uses a penalty factor which makes the densities upon which it is used, to be closer to 0/1. Another approach is the Geometry Projection [2] was initially introduced for shape optimization. In this approach, a sampling window is considered which computes the volume fraction enclosed by this sampling window. Another latest method is the Moving Node Approach (MNA) in which the components are considered as nodes and the move around to find an optimum solution. The above methods give a similar solution but the method used to implement the solution are different. In order to make it easier, a new method is proposed called Generalized Geometry Projection (GGP).

Additive Manufacturing (AM) is a fast developing technology as it carries high value in terms of weight and time for production. Also most of the AM technologies are able to produce highly complex geometries with high accuracy and efficiency. The process of AM is to add materials layer by layer to obtain a final 3D model. This technique is free-form as compared to other conventional manufacturing techniques.

2 STATE OF ART

2.1 General study

Topology Optimization can be understood by realizing the scheme of the problem. The main idea for this is declare the domain in which the work has to be done (in R^2 or R^3). In this domain, the optimal material distribution has to be figured. The mathematical expression for any load bearing structure is given by, [3]

$$\min_{u \in U,\Theta} \int_\Omega \rho u . d\Omega + \int_{\Gamma_T} t u . ds$$

Subject to, $\int_\Omega C_{ijkl}(x)\varepsilon_{ij}(u)\varepsilon_{kl}(v) \cdot d\Omega = \int_\Omega \rho v . d\Omega + \int_{\Gamma_T} t v . ds \ for \ all \ v \in U$

$$C_{ijkl}(x) = \Theta(x) C^0_{ijkl},$$

$$\Theta(x) = \begin{cases} 1 \ if \ x \in \Omega^m, \\ 0 \ if \ x \in \Omega \backslash \Omega^m \end{cases}$$

$$Vol(\Omega^m) = \int_\Omega \Theta(x) . d\Omega \leq V$$

$$Geo(\Omega^m) \leq K$$

U = Kinematically admissible displacement fields
u = The equilibrium displacement
ρ = body forces
t = boundary forces
$\varepsilon(u)$ = linearized strains
$Geo(\Omega)$ = constraint function to limit geometric complexity of the domain
$\Theta(x)$ = Pointwise volume fraction of the material
C^0_{ijkl} = stiffness tensor of a given elastic material

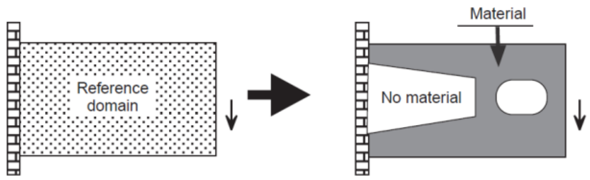


Figure 1 The generalized shape design problem of finding the optimal material distribution

2.2 The Solid Isotropic Material with Penalization(SIMP) model

This method implements a correction factor called penalty, which makes sure that the material density is restricted to either 0 or 1. The reason for doing this is to make sure the boundary can be clearly justified. So the value of this penalty p is generally taken as 3 or more and can be changed accordingly. Since a relative high value of p is used, optimizer is forced to find the best result. The element e is assigned a density x_e and gives Young's modulus E_e,

$$E_e(x_e) = E_{min} + x_e^p (E_0 - E_{min}), \ x_e \in [0,1]$$

Where,
E_0 = stiffness of the material
E_{min} = Small stiffness to avoid singular matrices
p = Penalisation factor

And therefore, the optimisation model then is formulated as:

$$\min c(x) = U^T K U = \sum_{e=1}^{N} E_e(x_e) u_e^T k_0 u_e$$

Subject to: $\frac{V(x)}{V_0} = f$

$$KU = F$$

$$0 \leq x \leq 1$$

c = compliance
U, F = Global displacement and force vectors

2.3 Generalized Geometry Projection (GGP)

There are several methodologies that are present in structural optimization. The review for this methodologies is done based on Geometric Projection (GP), Moving Node Approach (MNA) and Moving Morphable Components (MMC) frameworks. Considering these 3 frameworks, Generalized Geometric Projection is formulated.

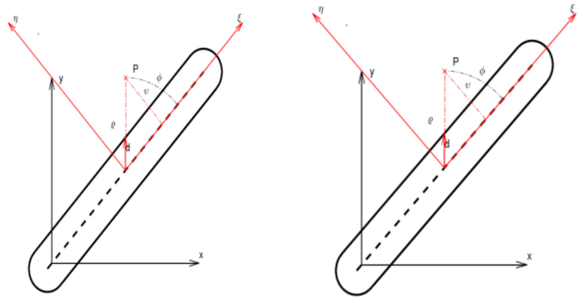


Figure 2 Geometric parameters

The classical equation which minimized the compliance of the structure is considered.

$$min_{\{x\}} C = \{U\}^T \{F\}$$
$$\text{S.t. } V = \frac{\sum_{el=1}^{N} \rho^{el}}{N} \le V_0$$
$$\{l_b\} \le \{x\} \le \{u_b\}$$

In the above equation, $\{l_b\}$ *and* $\{u_b\}$ are the lower and upper bound vector of design variable and V_0 is the maximum volume fraction.

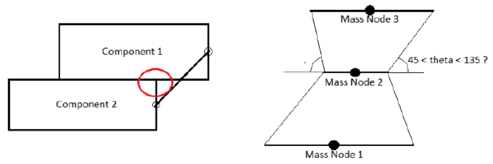
2.4 Additive Manufacturing (AM)

Additive manufacturing or Additive Layer Manufacturing is method of later by later manufacturing where the materials are added one layer after another. Unlike the conventional manufacturing methods, where the material is removed, this process is more efficient, light and is able to generate complex structural components with more efficiency and accuracy. In this, main problem is the overhang constraint in AM, for which several support structures are also printed. Generating structures with the support results in many post processes and might create rough surface. So one would like to eliminate this support material by limiting the overhang to certain value of this angle. It is studied that the maximum achievable overhang of printed parts is around 45° [4].

3 DEVELOPMENT

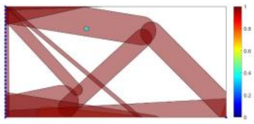
The use of GGP we can arrive at a solution for the problem formulated for the Additive Manufacturing. The primary idea for the overhang problem is to represent the solution using printed pathways and for this 1D components are considered.

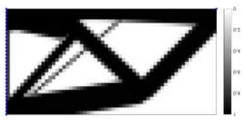
The 2 constraints for the development of this problem is $\theta \geq 45°$ and $\theta \leq 135°$. The previous work done is for the MNA code in 2D using these 1D component. Using the MATLAB code of the GGP, the constraints need to be added and the problem will be solved and it will be faster than the previous solution.

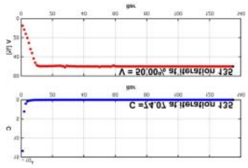


4 RESULTS

The main intent of the project was to understand the entire working of the topology optimization. The implementation of the GGP for a simple Moving Morphable Bars (MBB) is shown below with $N_{GP} = 2$ *and* $R = 0.5$ showing component plot, density plot and convergence plot.







With the variation of the number of gauss points and the sampling window, better results are obtained for different test cases.

5 CONCLUSION

The present project tells the use of topology optimization and the development of a new method in GGP. The implantation of the problem of AM using the MNA code can be improved using the new code. This work will be done further along with some additional work. This can then be implemented for other manufacturing constraints problems.

References

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