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Implementation of molding constraints in topology optimization

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Key words: Topology optimization, injection molding, manufacturing constraints

Summary In many cases the topology optimization method yield inadmissible solutions in respect to a particular manufacturing process, e.g. injection molding. In the present work it is chosen to focus on the most common injection molding parameters/factors determining the quality of the mold geometry, i.e. uniform thickness, filling of the die and ejection of the molded item, i.e. extrusion. The mentioned injection mold parameters/factors are introduced in the topology optimization by defining a centerline of the initial domain and then penalize elements in respect to the distance to the defined centerline of the domain.

Introduction

One of the widely used processes for manufacturing is injection molding. In this paper an effort is made to implement constraints given by the process of injection molding into the process of topology optimization. Introduction of manufacturing constraints have been considered by Ishii et al [3] which proposes a modified frame based unit cell approach providing symmetrical cross sections. Also commercial topology optimization software include methods to impose manufacturing constraints as devised by Schramm et al. [4], [5] suggesting a coupled topology-size approach. In the present work the topology optimization method developed by Bendsøe et al. [1] is used as basis.

Algorithm to impose injection molding constraints in topology optimization

An algorithm implementing molding constraints in the process of topology optimization is described shortly in the following. The approach is to define the structures center lines on the background of topology optimization and using those lines to weaken the sections, which would make the injection molding of the solution difficult or impossible.

The use of lines

By defining the center lines of the structure the following constraints of the injection molding process can be easily implemented:

- Filling of the die: I there are a uninterrupted lines from the user defined placement of the injection nozzle to all parts of the structure, than the liquid material can fly in all parts of the structure in the molding process.
- Direction of draw: If the lines are limited in a way that respects the direction of draw, the possible ejection of the item is guaranteed.
- Uniform thickness and no intermediate densities: If all elements, which center point is closer to the line than half the thickness, are assigned with the density 1 and all others with the density 0 (or a very small value to avoid singularities), then the resulting item is of uniform thickness and does not contain intermediate densities.

The definition of lines

At each step of iteration the lines are defined subsequently starting at the user defined placement of the injection nozzle by adding the neighboring node, which both respects the angle of draw and is assigned with the highest density. The nodes are assigned with the average density of the elements, which center points are within the circle with the diameter of the thickness.
The node is not obtained in the line, if the assigned density is lower than a certain value, in the used cases 0.2.
If two neighboring nodes have the same assigned density, the circle's diameter is increased.

Adjusting the compliance sensitivity

The compliance sensitivity of an element is adjusted in respect to the distance between its center point and the line:

$$\frac{\partial obj\ \rho_e}{\partial \rho_e} = \begin{cases} \dfrac{\partial obj\ \rho_e}{\partial \rho_e} & \text{if } dist_e \le \dfrac{t}{2} \\ \dfrac{\partial obj\ \rho_e}{\partial \rho_e} \cdot \left(\dfrac{t}{2 \cdot dist_e} \right)^{\max\ 1;n_{\text{it-steady}}-30} & \text{if } dist_e > \dfrac{t}{2} \end{cases} \tag{1}$$

In this equation the expression $\frac{\partial obj\ \rho_e}{\partial \rho_e}$ is the adjusted sensitivity for the element 'e', $\frac{\partial obj\ \rho_e}{\partial \rho_e}$ is the unadjusted sensitivity for the element 'e', t is the user defined thickness, $dist_e$ is the distance form element 'e' to the line, $n_{it-steady}$ is the numbers of steps of iteration where the line was kept unchanged.

Definition of the volume fraction

The volume of the structure is defined by the sum of all elements' volume, which centre point is closer to the line than half of the thickness and a tenth or a thousandth of the other elements volume, if the line length is increasing or steady respectively.

$$v_{fr} = \frac{\sum_{i=1}^{N_{el}} v_i \cdot \rho_{\left\langle 0/1 \right\rangle i}}{\sum_{i=1}^{N_{el}} v_i}, \text{ with the function } \rho_{\left\langle 0/1 \right\rangle i} = \begin{cases} \left\{ \begin{matrix} 0.1 & \text{if } n_{\text{steady}} \le 30 \\ 0.001 & \text{if } n_{\text{steady}} > 30 \end{matrix} \right\} & \text{if } dist_i > \dfrac{t}{2} \\ 1 & \text{if } dist_i \le \dfrac{t}{2} \end{cases} \tag{2}$$

Advantages of this algorithm

The solution from this algorithm is always an item, which easily can be manufactured by the process of injection molding, has uniform thickness and the ejection is possible. It is optimized by the process of topology optimization within the limits given by the manufacturing constraints.

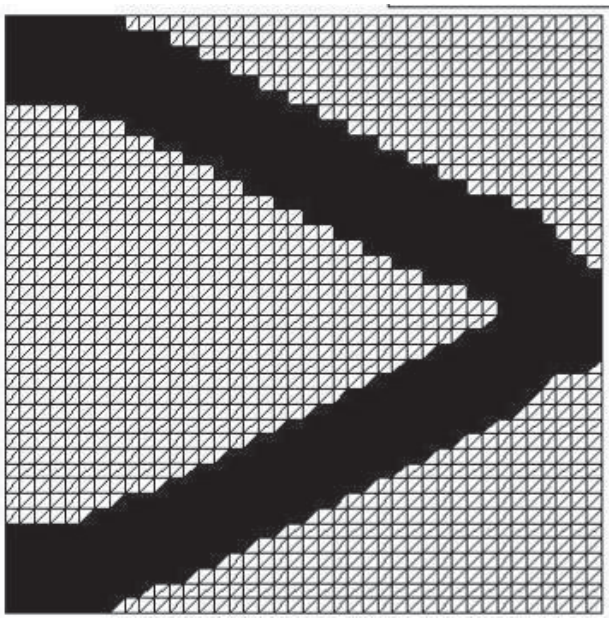
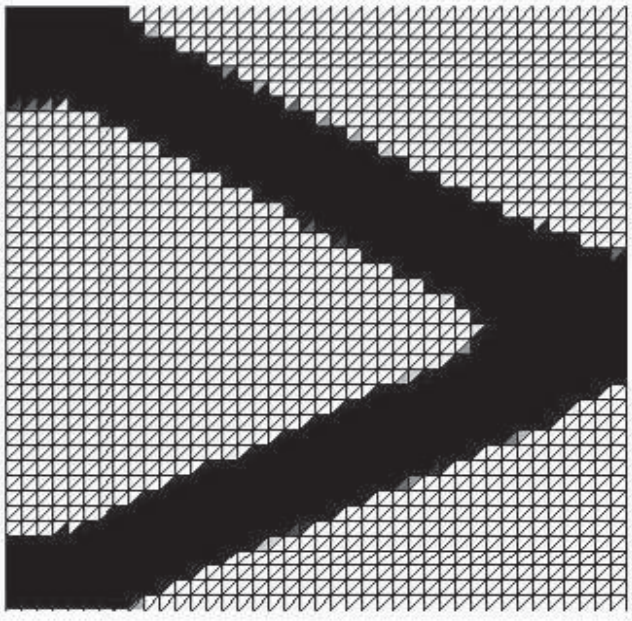
Because the combination of line and thickness defines, which elements are kept and which elements are left out of the solution, the method of SIMP is dispensable.

Disadvantages of this algorithm

The algorithm increases the calculation time, because the line has to be built up sequentially in every step of iteration and this includes assigned nodes with density. Afterwards the compliance sensitivity of all elements is adjusted in respect to the distance between the element's centre point and the line. The calculation time is not increase heavily compared to other filtering methods.

Verification of the algorithm

The algorithm is verified by a standard case, a quadratic cantilever beam with the force applied in the center of the free side. The algorithm's result is compared to the result found by the topology optimization process with Esbjerg filtering and the SIMP-penalty of 3.5.

New algorithm	Esbjerg filtering SIMP-penalty p=3.5
	
After 83 steps: Overall change of density < 1/10,000	After 122 steps: Overall change of density < 1/10,000
Compliance: 20.6321-20.6810	Compliance: 19.8397-20.1115

The solution of the Esbjerg algorithm has a compliance of ca. 20, while the new algorithm is a little weaker with compliance of 20.7. In the Esbjerg filtering the higher value of the compliance is the value shown after optimisation, still under the SIMP penalty. The lower value is cleaned for this influence. The little difference shows, that a few elements have intermediate densities.
The lower value in the new algorithm is the compliance of all the elements assigned with the density 1, while the higher value is the compliance for all elements.
In respect to the limitations to the new algorithm this seems reasonable. The difference in the compliance can be explained with the areas above and below the centre of the right edge. Here the Esbjerg filtering has material, which violates the limitation of uniform thickness. Therefore these areas are not a part of the solution of the new algorithm. At the upper right corner there is an area below the dark area, which is dark in the solution of the topology optimisation using the Esbjerg filtering. This area and the similar and the lower left corner violate the direction of draw and are therefore not a part of the new algorithm's solution.

Concluding remarks

The new algorithm might be a useful tool for developing and optimizing items, if it is integrated in commercial software. Instead of strengthening or weakening individual elements, the process works on sections.

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