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Design optimization of plastic injection tooling for additive manufacturing

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Abstract

This work presents a systematic and practical finite element based design optimization approach for the injection tooling adaptive to additive manufacturing (AM) technology using stereo-lithography (SLA) and powder bed fusion (PBF). First a thermomechanical optimization of conformal cooling is implemented to obtain the optimal parameters associated with conformal cooling design. Then, a multiscale thermomechanical topology optimization is implemented to obtain a lightweight lattice injection tooling without compromising the thermal and mechanical performance. The design approach is implemented to optimize a real design mold and the final optimal design is prototyped in SLA and the manufacturability in PBF has been discussed.

Keywords: injection tooling; conformal cooling optimization; topology optimization; additive manufacturing

1. Introduction

The creation of production tools for prototype and production components represents one of the most time consuming and costly phases in the development of new products. To reduce the manufacturing lead-times and cost, prototyping and manufacturing processes has already been rapidly developed and integrated to the manufacturing progress. One of the important applications of prototyping and manufacturing processes is to product injection tooling. Based on current additive manufacturing (AM) technologies, up to 50% in time and cost in tooling production can be saved [1]. The outstanding advantage of using AM to fabricate injection tooling is the effectiveness to obtain complicate geometries of the master pattern and its conformal cooling channels. Furthermore, the utilization of AM offers an opportunity to produce lighter and more efficient molds and dies composed of lattice structure that saving the material used in AM process. With the development of finite-element based structural

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optimization methods, it is possible to improve the design of today's injection tooling and create lightweight, complex designs with higher thermomechanical performance.

In the earlier work [2], we propose a framework for optimizing the design of Injection tooling with conformal cooling for additive manufacturing. In this study, we improve this concept to develop a finite element based approach to find the optimal parameters for the conformal cooling channels, as well as optimal functionally graded lattice unit cell distribution of the mold body. To achieve this, thermomechanical optimization problems associated with design geometrical parameters are formulated. The optimal design parameters can be obtained by using derivative-free optimization solvers. Then, the design domain of the mold with optimal conformal cooling is optimized to a structure composed of solid and lattice phases of unit cells. The manufacturability of the final optimal structures are discussed and will be demonstrated in the future work.

This work is presented in next sections. First, a literature review about is presented in section 2. In section 3, the procedure of thermomechanical conformal cooling for a real injection tooling is described. Section 4 presents the proposed multiscale thermomechanical topology optimization for this injection tooling. Section 5 shows the design prototype and the discussion of manufacturability. Finally, in section 6 conclusion are given.

2. Literature review

2.1. Thermomechanical optimization of conformal cooling

Conformal cooling is defined as the cooling channels that conform to the surface of the mold core (or cavity) for efficiently transferring the heat from the mold core to the coolant channels, aiming to maintain a steady and uniform cooling performance for the molding part [3]. Compared with conventional cooling, conformal cooling can often result in reduction of production cycle time, warpage and shrinkage, which in turn may provide financial benefit to industries. Nowadays, the unique capabilities of AM technologies allow an innovative design approach that challenges traditional guidelines of the plastics injection molding industry. Research has indicated significant advantages of AM generated, highly complex conformal cooling channels. In research, computer generated molds designed with conformal cooling channels have exhibited increased thermal and mechanical performance and indicate a reduction of material and manufacturing costs. The optimization of these conformal cooling channels can be considered a finite element-based parametric task, with optimal parameters obtained using either of Design of Experiment (DoE) or non-gradient based optimization algorithm. Choi et al employed a commercial process integration and design optimization tool called Process Integration, Automation and Optimization (PIAnO) to perform parametric study for mold cooling optimization [4]. Ramos et al propose a multi-objective genetic algorithm called NSGA-II to obtain the optimal parameters in the optimal mold design [5]. Simulations have shown that these designs have reduced cooling time, improved temperature uniformity and reduced volumetric shrinkage. However, these optimizations have lack adequate stiffness to ensure structural stability of the injection mold. An injection mold is also subjected to high levels of pressure from the heat polymer melt as well as clamping force, which may be arising high von Mises stress and deflection on the surface of the molds and pipes. In this study, a thermomechanical optimization is implemented to obtain not only an optimal design has both thermal performance, but also a design enables to withstanding pressure mechanical loads and thermal expansion during the injection molding cycle.

2.2. Multiscale thermomechanical topology optimization

Among currently available finite element-based design methods, topology optimization is recognized to provide innovative, high-performance layouts that are suitable to AM. Integral to the proposed design process is the use of multiscale thermomechanical analysis for mechanical and thermal properties. The term multiscale refers to two length scales: mesoscale and macroscale. Mesoscale refers to the length of a unit cell. At the mesoscale, lattice unit cells are analyzed in order to derive homogenized thermal and mechanical properties as a function of their relative density. These homogenized properties are derived from asymptotic homogenization methods [6]. The shape of the materials is regular and controlled by a few of geometric parameters that define a potentially large range porosity. The material interpolation is modified to guide a macroscale structure consisting of only the discrete set of a priori