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Development of SLM cellular structures for injection molds manufacturing

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Abstract

Using selective laser melting (SLM) is possible to manufacture molds with cellular internal structures with different porosity degree. Furthermore, internal geometry design can be improved as a function of the desired structural and thermal stress solicitations. In this work two types of cellular internal structures – hexagonal and cub-octahedral – were developed and manufactured using the SLM process. These topologies were generated with the purpose of creating a high degree of internal porosity and getting satisfactory results in terms of thermal and mechanical behavior when compared with similar dimensional bulk structures. The mechanical and thermal behaviors of each cellular topology were evaluated numerically and experimentally through compression and thermal tests. From numeric and experimental results, it can be concluded that hexagonal cellular internal topology provides a higher mechanical strength when compared to the cub-octahedral cellular structure while the thermal analysis shows that cub-octahedral topology is more efficient for heat dissipation. Both cellular topologies have demonstrated, however, to be appropriate for use in injection mold structures. In addition, the use of these cellular topologies provides light weight structuring with an approximate 58% weight reduction, which represents a considerable saving of material total cost to manufacturing of an injection mold.

Keywords: Cellular structures; SLM; Injection molding; Finite elements; Mechanical and thermal experimental behaviors

1. Introduction

Consumers are increasingly demanding about the quality of products that they purchase. This reaches a real challenge for the technology of molding by injection of polymeric material. Injection molding has currently a high level of commercial importance as it allows for the acquisition of parts with high dimensional accuracy at high production rates. The need to produce more parts with high quality in a short period of time at a lower cost implies the optimization of injection systems. To ensure dimensional and structural quality of the parts produced, conditions such as the following must be met: (i) the mold must have a sufficiently rigid structure; (ii) the guide that aligns the cavity with the bushing must ensure a perfect alignment; (iii) the power required must be such that the path of the molten material from the nozzle of the injector to the cavity is constant; (iv) the mold temperature should be uniform in part surfaces to ensure that cooling is rapid and efficient; (v) the extraction of the mold parts must be made so that they are not damaged [1,2].

The temperature control of the mold during the injection process is a determining factor for obtaining parts with a good finish and dimensional accuracy. This control is also crucial to reduce part of the cooling time so that it can be removed as soon as possible [2–4]. Optimization of mold cooling processing can undoubtedly lead to a reduction of the effective total time of the injection process, enabling a shorter manufacturing time which leads to a reduction of production costs. Beyond this critical aspect, there is still the issue of the weight of a structure of a mold. This type of structure is until now fabricated by conventional production processes, starting from a steel block and subtracting material to achieve the desired shape. This procedure leads, however, to very high costs of the production tool, to the extent that production becomes a slow process and requires skilled labor at all stages thereof. After finished, the mold is presented with a bulk and heavy structure, difficult to transport and put in injection equipment. The use of cellular internal structures

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obtained by Additive Manufacturing (AM) processes could optimize the weight of these structures and make a mold into a more sustainable product.

Among AM techniques, selective laser melting (SLM) offers a wide range of advantages, e.g., lower time-to-market, high rate of use of materials, direct production from three-dimensional CAD model, high level of flexibility, i.e. products with different geometries can be produced in the same batch, flexibility of the material being processed, high flexibility in the selection of metallic materials to be used (aluminum, copper, iron, stainless steel, chromium, nickel alloys, titanium and composites of these materials), high production rates, mass customization, versatility, precision, geometric freedom, and the ability to create unique designs with intrinsic characteristics of engineering [5–11]. This explains why, in recent years, the SLM has proven to be among the most efficient additive processes for the production of metal prototypes and parts with complex geometries and has been widely applied in different areas of industry, e.g., automobile, aerospace and aeronautics, construction civil, textile, retail, medicine and, more recently, in the production of scaffolds in engineering of human tissues and teaching [12–21]. In addition, the ability to create functional components with mechanical properties compared to the properties of powder materials that gave rise to these, or even the creation of components with improved surface properties such as hardness, abrasion resistance and corrosion, among others, gives to SLM a prominent place within the range of AM techniques. Allied to these advantages, it is also unquestionable that another great advantage of SLM is associated with the production of components with high mechanical strength through the generation and optimization of internal topologies consisting of thin walls, hidden voids and channels, i.e., with a specific porosity degree, which represent a global reduction weight of components, without loss of stability, reliability and mechanical strength of produced parts [11,13,21–24]. This approach is particularly relevant to the industries related to injection molding and molds production where cellular internal structures can be used instead of bulk parts. Regardless of geometry complexity, the use of SLM in the production of molds allows the optimization of the design of cooling channels, which ensures injection product quality and increasing productivity [25].

The purpose of this work is therefore the study of alternative cellular internal structures of a mold in order to be able to withstand the injection pressures and additionally increases the thermal efficiency thereof without loss finish quality. The cellular internal structures developed are lattice volumes with conformal cooling channels configured according to injection molding procedure. In short, it is intended to choose an internal structure for a mold allowing the reduction of weight and the amount of material in the production of the mold, as well as an improved thermal behavior of the structure so as to lead to the manufacturing of products with better quality and high production rates. To achieve this, two mold inserts with high degree of internal porosity, were developed and produced using the SLM process. The mechanical and thermal behaviors of each one were evaluated numerically and experimentally through compression and thermal tests.

2. Design of internal cellular structures

The possibility of producing prototypes with high porosity, but also resistant, through internal topologies modeled in the design phase, is one of the great advantages inherent in SLM manufacturing processes [11,13,21–24,26–28]. The purpose of this study is to demonstrate that the application of these concepts in the molds industry may eventually allow for the production of significantly lighter and functional molds with an improved thermal performance without production reliability loss.

One way to modeling internal topologies is from Boolean operations, through the union, subtraction or the intersection of two or more entities or objects [26]. However, for this work it was decided specifically to set aside this mathematical tool and opt for the root of the unit cell lattice structures geometry modeling using a 3D Computer Aided Design (CAD) software – SolidWorks®, and amongst these, stochastic porous structures were not considered. In fact, periodic cellular lattice structures are light-weight structures that seem to provide advanced or multifunctional performance for high value engineering products, such as injection molds, rather than those achieved with stochastic porous structures [22,23].

For the development of cellular topologies design – periodic cellular structures, using a 3D CAD tool, the first phase involves the creation of an inner unit cell structure model. This step is proceeded by units aggregation to create a 3D block composed of several structures until the desired dimensions are reached, i.e. specimens are building repeating units in the three different directions originating a cohesive whole in which all units are in contact within each other surrounding units [23,29]. Moreover, it is necessary to ensure connectivity between several unit cellular structures in order to obtain a rigid global structure with stable and homogeneous mechanical properties.

References [28,30,31], for instance, presented a detailed review on cellular internal structure architectures produced by AM technology, e.g. cylindrical, hexahedral, octahedral, dodecahedra, and so on. Based on the research conducted to select proper internal geometries to be used in injection mold fabrication and manufactured by SLM process, two distinct unit cells with different internal topology were designed: (i) a cub-octahedral unit and (ii) a hexagonal unit as shown in Fig. 1a and b, respectively. The cub-octahedral unit selection was based on lattice structures due to its well-known good mechanical behavior [11,22,32]. The second structure – hexagonal cellular unit – gets its inspiration from nature, specifically in honeycombs created by bees.

Cellular structures have been widely used as energy absorbers to withstand external loads, due to its high energy absorption capacity [11,13,21–24]. The mechanical behavior of this type of structure geometry has also been the target of a strong study over the years [11,23,27,28,31,33–37].

In order to perform the study of mechanical and thermal behavior of parts with internal structures built with unit cellular structures shown in Fig. 1a and b, it was necessary to design test body by repetition of each respective unit. Fig. 1c and d