Sustainable production of injection moulds through additive manufacturing and improved application of energy management

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Abstract

The concept of this thesis is to optimize the manufacturing process of injection moulding tools by using additive manufacturing and thus contribute to environmental protection. For this purpose, the individual steps of the traditional manufacturing process are identified and analysed to determine which steps can be replaced by additive manufacturing. The first step is to clarify which mould components can benefit from additive manufacturing. In particular, the capabilities and limitations of additive manufacturing technologies must be considered.

Furthermore, another focus is on how to optimize the cooling and temperature control of the tools. Potential savings through the use of lightweight or insulating surfaces will be examined. In addition to the technical feasibility, the cost-effectiveness of the concept will also be considered. Finally, the contribution of the concept to the reduction of the environmental impact will be evaluated. In particular, energy savings and the reduction of CO_2 emissions are taken into account.

The potential to optimize the injection mould manufacturing process and reduce environmental impact is significant. Using additive manufacturing can be an economic and environmental advantage.

Introduction

Injection moulding is the process for the mass production of ready-to-use moulded parts. Plastic is heated and injected under high pressure into a mould. The cavity determines the surface texture and shape of the part. Injection moulds are made using many different manufacturing processes (Dolmetsch, H. [DoH], 2007). Using additive manufacturing to produce this mould can lead to more efficient injection moulds in terms of energy and resource savings. This paper will highlight the environmental impact and suggest improvements. The knowledge gap on energy and material savings during the manufacturing process will be further explored in this and future work.

Additive manufacturing (AM) is the process of creating an object by building it up layer by layer. It is the opposite of subtractive manufacturing, where an object is created by cutting away from a solid block of material (Linke, R. [LiR], 2017). To create a part using

AM, you first need a design. This is usually done using computer aided design (CAD) software. Generative design and simulation can be used to create the optimal shape of the object.

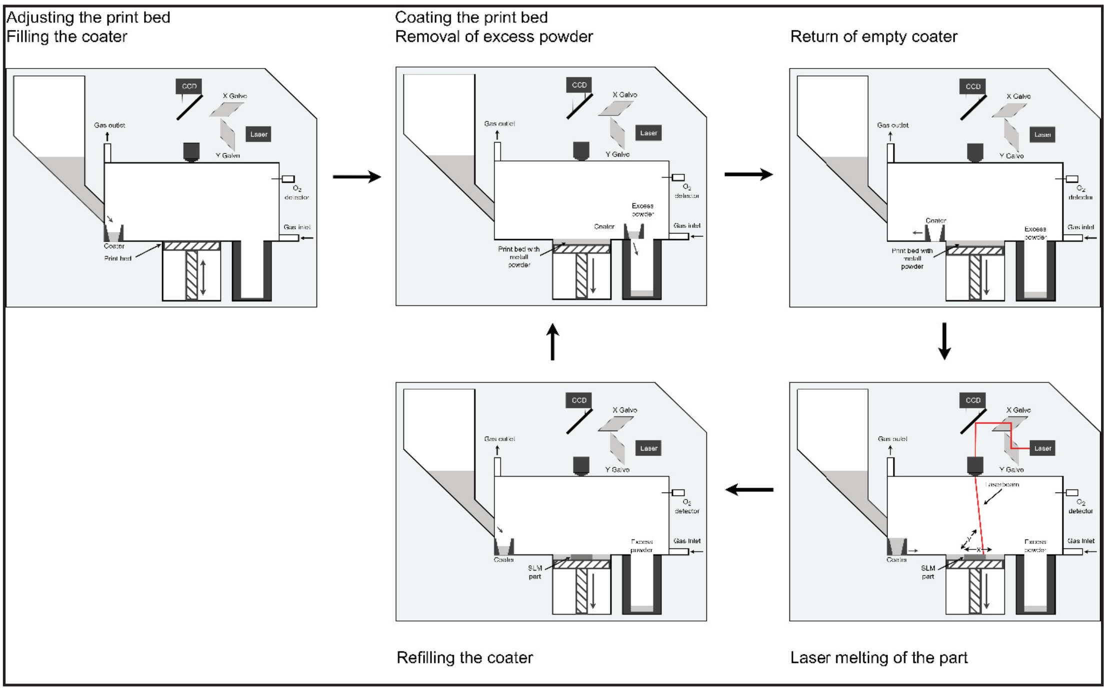

Figure 1: Workflow selective laser melting (SLM)

The entire process is carried out using Selective Laser Melting (SLM) to achieve an efficient tool in terms of rapid cooling. SLM is used to produce near-net-shape parts with good surface quality. This means that the initial manufacture of a component should be close in size and shape to the finished product (Sefene, E.M. [SeEM], 2022). Metal is used for printing injection moulds. The workflow of an SLM printing process is shown in Figure 1. The first step is to set up the print bed and fill the coater with metal powder. Then the first layer is applied and the excess powder is collected. The coater is then returned to its starting position. A laser is used to melt the first layer of the finished part. The build module moves down a few microns (e.g. MPRINT+: 0.45 µm particle size, 0.4 µm height) in the z direction. The coating, melting and positioning processes are repeated until the part is complete. The advantages of SLM for the proposed application are described below. The ability to create complex structures is the main focus. AM can be used to create internal structures that cannot be realised by subtractive manufacturing, such as internal and lightweight structures. Its implementation in lightweight construction is discussed in more detail in the Methodology section. In addition, SLM can enable the rapid production of the designed part and save on supply chains. On the one hand, this leads to shorter operating and transport times, and on the other, to energy savings. Additive manufacturing allows the product to be tailored to the application. Replaces subtractive manufacturing operations such as milling, turning, grinding and EDM. In addition, the post-processing steps of the 3D printed part must be added and considered. The lightweight design reduces the amount of material used and the weight of the finished tool. (Sculpteo [Sc], 2021). All these facts lead to the point that additive manufacturing in injection moulding tools can achieve improved energy management.

During the injection moulding process, energy can only be gained by reducing temperature losses. By making moulds more efficient in terms of cooling or isolating certain layers, the cycle time (time unit per moulded component) can be reduced and thus the energy used per part. The following section discusses cooling and insulation options in more detail.

Methodology

Injection moulding is a high-energy process that involves melting the plastic and injecting it under pressure into a mould cavity, followed by cooling and ejection of the solidified product. The extracted heat is of low quality, and attempts to recover it are rare, but there is room for improvement in energy efficiency through careful equipment design and process operating parameter selection (Rashid O., et al. [RaO], 2020). High pressure, high temperature and force are the key process parameters that an additively manufactured injection mould must be able to withstand. It is important to include these in the design process and find the best structure through FEM and optimisation.

Stoll et al. investigated the use of SLM to realize porous structures. Pores can be used in liquid flow applications as microchannels. Which laser parameters have an effect on the labyrinthine structure are described. The line spacing and laser spot diameter have an effect on the formation of stochastically distributed porosity up to the formation of lattice and lamellar structures (Stoll, P. et al. [StP], 2015). Siemann emphasized other applications of porous structures. Using mould making as an example, laser sintering was used to create venting elements. Air pockets, particularly in micro-injection moulding, can cause defects in the finished part (Siemann, E. [SiE], 2007). As a result, in the search for more efficient moulds, this application should not be missed and should also be used in future experiments. Lightweight parts can be created using additive manufacturing technologies. AM technologies have enabled the production of complex cross-sectional areas such as the honeycomb cell or any other material part with cavities and cut-outs that reduce the weight-strength relationship. It is possible to create lightweight structures for obtaining a shape with a minimum weight and a very difficult shape of a structure that has been used for civil construction; however, with AM, it is possible to create structural parts for machines while reducing total weight. . If at all possible, these complex shapes will be expensive to create using the traditional process. These kind of complex shapes were created using the traditional method. These structures will be costly to build if at all possible with subtractive manufacturing (Wong K.V. et al. [WoKV] 2012). On the one hand, porous structures and lightweight construction can improve the efficiency in terms of energy savings of the manufacturing process. This is because the printing time in SLM is reduced and material is saved. On the other hand, it is interesting to investigate the insulating properties of these layers. Insulating areas in the injection mould can influence the solidification process as the plastic material cools, leading to improved properties in the finished part. This is going to be investigated in further work.

Cooling channels can be integrated into the mould close to the contour using additive manufacturing. During the injection moulding process, coolant fluid flows through these channels to remove heat. The cavity can be cooled more efficiently due to its proximity to the contour (Wahl, J.P. et al. [WaJP], 2020) (Zimmermann, T. [ZiT], 2011). The combination of insulating layers and cooling channels close to the contour is to be used for more efficient injection moulds. Overall, such a structure can only be produced using

AM especially SLM. To further increase efficiency, force simulations will be used to determine the best use of lightweight construction, and temperature simulations will be used to identify the best use of insulation layers and cooling channels.

Conclusion

Injection moulding process times should be shortened as a result of more effective moulds. This results in cost savings throughout the process due to a decrease in uptime and energy usage. Improved sustainability is a result of greater throughput (number of components moulded per unit of time). Also, the entire manufacturing process is sped up by additive manufacturing using selective laser melting. Improved energy management is expected due to the elimination of transport routes and supply chains. With SLM, the entire manufacturing process can be carried out in a single step. Material and weight savings increase the efficiency of SLM and conserve resources.

The concept offers great potential for optimising the manufacturing process of injection moulds and thus reducing the environmental impact. The use of additive manufacturing can be both economically and environmentally beneficial. However, further research and development is required to establish the technology in practice and to realise its full potential.

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