

CONSTRUCTIVE, DESIGN AND TECHNOLOGICAL CONSIDERATIONS FOR THE DESIGN OF INJECTION MOLDS MADE WITH ADDITIVE MANUFACTURING METHODS

Maria Monica Borleanu [1]
[1] Faculty of Mechanics Timisoara, Romania, maria.borleanu@student.upt.ro

ABSTRACT: The work is intended to be a study on the technological possibilities of injection moulds for plastic, but also metal materials through additive manufacturing. This is structured in four chapters, starting from the theoretical and constructive considerations of the components of such a plastic deformation processing process and then analysing the main mould generation technologies that can be used to achieve the final goal. Finally, the design procedures for small-sized injection moulds are analysed, but they can also be medium-sized designed by the same process. The results obtained in this way will be concretized in laboratory studies where, both from the point of view of the material used to make the moulds, and of the one that will be injected inside them, the way of evolution and the dimensional and mechanical characteristics of the made landmarks will be followed.
KEYWORDS: DLP and MSLA, CAD, CAM, 3D modelling, injection.

1. INTRODUCTION

A die is a device specially designed for manufacturing industries to modify the form of a material to the desired shape or profile. Unlike direct moulding of complete parts, mould is used to form the planar dimensions of a part. The third dimension, usually thickness, length, or profile, and is controlled by other variables of the machining process [1, 3].

Designing a die is represents an essential step both in the manufacture of plastic components by injection, as well as in the production of other products, such as ergonomic mobile phone cases, dashboards necessary for the construction industry cars or children's toys. If, until recently, the recipe for success in business was the launch of a superior quality product on the market, with production costs and a manufacturing time lower than those of the competition, nowadays it has been proven that this is no longer enough. Now the focus is on innovation, on variety so that manufacturers launch new products that easily penetrate the market. This market pressure is reflected in the entire production chain, reaching the suppliers of moulds and components for them.

Thus, mould designers are also faced with a real challenge. The design, the development of technical documentation and the making of moulds have evolved from the planchet to 2D/3D CAD systems. The increasing complexity of the products' shape has imposed the most complex modelling as effective solutions in the design stage of the active parts of the mould. To achieve a more efficient design, we reached the situation of combining a 3D model for the active parts with 2D representations, developed unrelated to the previous one. Many advanced CAD/CAM computer tools are available today – AUTOCAD, CATIA [3], FUSION 360.

Additive manufacturing technologies have gained momentum on a global scale in recent times due to the opportunities and benefits they bring to the fields of engineering, medicine, the food industry, and finally, the fields of construction and fine arts. The flexibility in making products or parts with complex shapes, the variety of techniques for making the external design of the product or part and, last but not least, the possibility to change the shape of the finished product without the need for further preparation its additive manufacturing are the major advantages of a manufacturing technology that makes the transition from single production to the other types of production, serial or mass production. The process of additive manufacturing is characterized as technologies dependent on a 3D modelling program and a user who has advanced skills in using these technologies. [5]

2. CONSTRUCTIVE CONSIDERATIONS FOR THE GENERATION OF MOLDS THROUGH ADDITIVE MANUFACTURING

For constructing an injection mould several factors have an important influence, like cost-efficiency and product characteristics. The volume of them but at the same time the material of the mould can also have an important influence, as most materials have differing levels of wear resistance, making them suited for long-term, high-volume production [7].

The material from which the moulds are made are:

- moulds obtained from different iron alloys processed by cutting on CNC machine,
- moulds obtained from other metals by the quick manufacturing technique by spraying molten metal called metal spraying,
- silicone rubber used for mould generation,
- moulds made of special plastic materials,
- moulds made of composite materials [4, 5].

2.1 Moulds obtained from different iron alloys processed by cutting.

Cutting processing is an operation that changes the shape and dimensions of the workpiece - the mould. This processing is carried out on machine tools, with the help of cutting tools, and consists in the successive removal of layers of material, in the form of chips, until the desired shape and dimensions are obtained. The hardness of the cutting tool edge is superior to the hardness of the material to be processed. During the relative movement of the tool in relation to the workpiece (rotation, speed, feed), the cutting process takes place. Depending on the type of cutting, the cutting processes are divided into turning, milling, drilling, widening, reaming, grinding, grinding, hardening, broaching, mortising, threading, cutting, polishing.

The steps taken for chipping processing consist of: dimensional control of the semi-finished product, physical-chemical verification of the material and, possibly, its state of preservation; preparation and verification of the numerically controlled machine tool program; the actual processing, i.e. obtaining the mould, is carried out by the relative movement between the part (rotation) and the tool (forward) through one or more passes, depending on the size of the processing allowance and the quality of the surface; control: the mould is checked in terms of dimensions (tolerances) and surface quality with the help of measuring means with effective reading, verifiers, measuring and control devices, according to the documentation (operations plan, control plan, etc.). However, considering the energy consumption and the carbon footprint generated to obtain one kilogram of aluminium alloy, there is a current tendency to abandon such a solution and replace it as a material with other less polluting ones.

2.2 Moulds obtained from other metals.

Usually, aluminium alloys are used as a solution for making such devices, which can ensure the processing of materials with a low hardness, usually non-metallic or plastic materials. However, considering the energy consumption and the carbon footprint generated to obtain one kilogram of aluminium alloy, there is a current tendency to abandon such a solution and replace it as a material with other less polluting ones.

2.3 Silicone rubber used for mould generation.

The use of silicone in making moulds is more common in the moulding of plastic materials and less often in the injection part. However, this last mention cannot constitute a restriction considering the existence of the external metallic or non-metallic part supporting the injection mould.

2.4 Moulds made of special plastic materials.

The 3D printed moulds are more efficient from the point of view of energetical consume and carbon emission. The most common system for making mould with resin is the LED system with polymerization of the light usually named mask stereolithography (MSLA) or diode light polymerisation (DLP) printing system. Another solution for polymerization with laser light generated by a laser head which can make rotation or translation of the laser fascicle named stereolithography (SLA) printing system.

2.5 Moulds made of additive metal materials.

Another way to mould a die is with the help of additive materials named sintering with laser named selectively laser sinters (SLS) printing system. Metal additive manufacturing works in a similar way to plastic additive manufacturing, but instead of the commonly used plastics, different metal powders are used to form metal components. The metal powders used are made from different materials and can be selected in the right alloy to suit the desired workpiece and application. Thus, additive manufacturing can be easily transferred to other industries, as metal parts can withstand significantly higher stresses.

2.6 Moulds made of composite materials.

The use of composite materials allows the creation of moulds with greater rigidity than those made of usual materials and is found both in the making of moulds for moulding plastic materials and the injection part. This last mention allows us to state that the premises exist to use such moulds without necessarily needing the external support part to carry out the injection process of metallic and respectively non-metallic or plastic materials.

3. CONSTRUCTIVE CONSIDERATIONS ON INJECTION MOLDS THROUGH ADDITIVE MANUFACTURING

3.1 Analysis of the main constructive and technological methods that can ensure the production of injection moulds.

The additive manufacturing process is also well known as 3D printing because it creates 3D solids by an additive layered approach. Additive manufacturing is a digital manufacturing process because the digital stereolithography (STL) file (computer aided design (CAD) geometry) is rapidly converted layer-by-layer into a machine code (G-code or a set of successive pictures) for the generation of the solid body 3D printed. If it is taken into consideration that the traditional solution for mould is a computer numerical control (CNC) machine which has a program made with computer aided machine (CAM) and a set of tools required for working. At the same time the CAM analysis and simulations are imposed to determine if the working program is correctly conducted. In Figure 1 it is presented a short solution for CNC milling mould [9].

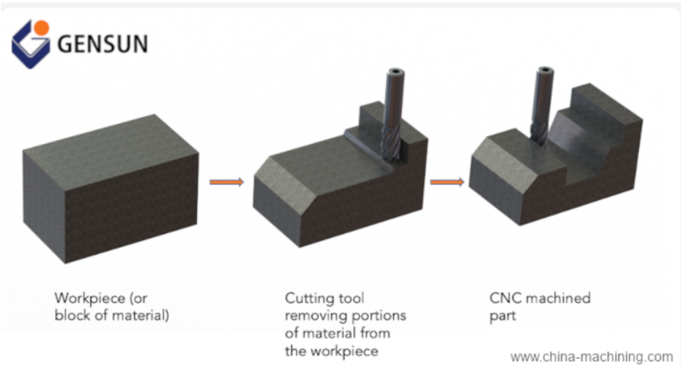

Figure 1. CNC machining process [9]

In the 3D printing process of die the digital data are directly converted in layer in which or by optical method (picture (MSLA or DLP) or G-code process (SLA)) can directly generated the part. In Figure 2 it is presented the MSLA or DLP printing process. Important to note it is the fact that in a layer simultaneous it is possible to printing multiple parts or bodies. For the SLA printing process Figure 3 which working with a laser focusing source for optical polymerisation the time to generate the parts bodies are biggest in rapport by the last presented process.

Focusing on the printing technology, in the case of Selective Laser Melting (SLM), a layer of powder is iteratively spread over a building platform and processed with a laser (powder bed fusion technology). According to the CAD geometry, the laser scans over each layer to melt each powder layer [2]. The 3D additive manufacturing process using metal can produce visually and physically impressive results. The metal is ideal for creating custom pieces that are resistant to heat, chemicals, and impact.

Advantages of 3D printing are diversity of the solution for created the part or body elements such as:

- FDM printers alone can print materials like polycarbonate, nylon, carbon fiber, wood PLA, PETG, ABS and PEEK,
- Resin printers MSLA or SLA can print with ecofriendly, dental, castable, or even ceramic resins,
- other 3D printers SLS or SLM can print metal, nylon, or ceramics.

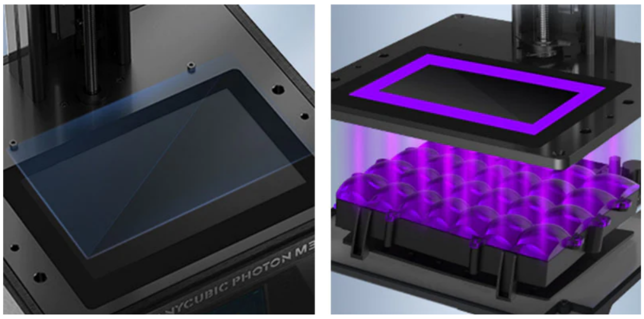

Figure 2. MSLA 3D printing process [10]

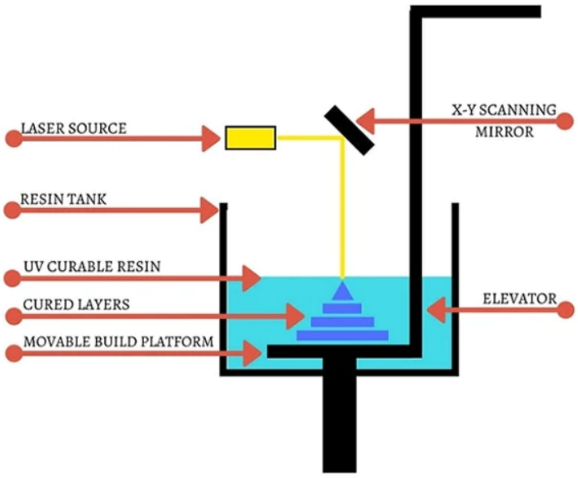

Figure 3. SLA 3D printing process [10]

Even if traditional moulds cannot create certain shapes, 3D printers use supports that can be removed in post-processing, allowing to produce parts with steep angles and overhangs. Subtractive manufacturing chops away at larger blocks, wasting these unused materials which is better for the environment. With 3D printing, only the exact quantities of material required are used, using less plastics and wasting less surplus material. Most of the plastics used in FDM printing are recyclable, and PLA filament is even biodegradable [6]. The 3D printers can create almost any shape, from a huge variety of materials, and can be post-processed further if necessary. It's can use by anyone which wish making parts, models and toys, the limits are just your own creativity [6]. It is important to observe that in the printing process taken into consideration, same of them are far too slow in producing large amounts of parts, because as not enough parts can be produced quick enough for mass production [6]. A major problem that the FDM printing process has is that of absorbing moisture from the air. This can affect the quality of the manufactured parts.

For CNC working parts the advantages are less than for 3D printing process. They considerably reduce the production costs allocated to mass production. They increase productivity because they can be used continuously. Considerably reduce the production costs allocated to mass production. Through the development of the software used, continuous improvements and improvements can be made [8]. Important to note is the aspects generated by the comparation with 3D printing, traditional cutting methods cannot use a varied range of materials [6].

3.2 Constructive solutions for making moulds through additive manufacturing with photopolymerization of their material.

In this paper the aspects of the MSLA 3D generation of die for mould are taken into consideration. The main reason for choosing this solution in relation to the other mentioned 3D printing options, are determined as can be seen from other studies undertaken [11-15], those related to the dimensional accuracy but also to the much higher printing speed compared to the other mentioned solutions.

Considering this last consideration, to make an injection mould composed of two parts, as can be seen from Figure 4, we need an outer structure made of aluminium or steel with the role of mechanical stiffening of the additively manufactured mould, respectively of the two half-moulds made by additive manufacturing inserted into the two stiffening half-cases.

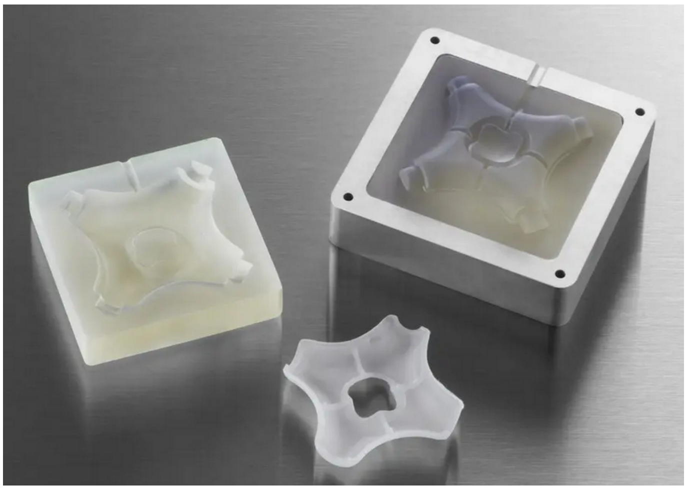

Figure 4. 3D printed injection moulds in an aluminium frame with the finished injection moulded part. [16]

3.3 Constructive CAD solutions for making moulds through additive manufacturing with photopolymerization of their material.

From the point of view of solutions for generating semi-moulds through the assisted design process, we have several solutions available. Some of these allow both moulding the mould, but also determining the thermal transfer and how the temperature that ensures the heating of the semi-moulds is distributed on the injection surface of the material. Among these, it is worth mentioning the integrated solutions provided by the programs SolidWorks, INVENTOR or Fusion 360. Other variants allow the same process to be carried out but using a program on the CAD generation side and another program respectively on the heat transfer study side. Among these we mention CATIA or Solid Edge on the CAD side and ANSYS on the modelling side.

3.4 Constructive generation of moulds with Fusion 360 product by additive manufacturing with photopolymerization of their material.

From the point of view of designing such an injection mould there are several possibilities.

The first of these is to make the semi moulds separately by profiling the inner part of the two parts and positioning the centring elements and positioning the semi moulds in relation to each other. The variant is laborious and, at the same time, labour-intensive and can generate some inaccuracies in the positioning of the landmark inside the assembled semi-moulds.

The second option that can be used is to make a 3D drawing of the landmark, followed by positioning it inside a parallelepiped element, centred inside it. Next is the positioning of a plane of separation of the parallelepipedal body at the level of separation into two parts of the landmark to allow both the opening of the semi-moulds, but also the extraction of the landmark from inside them. The process is much more precise than the first variant and at the same time ensures a very good precision of the mark made in the two half moulds.

The last variant is that of positioning the two half moulds on the opposite surfaces of the plane to be separated in relation to which the reference is also positioned. From the point of view of the landmark it can be separated into two parts or be positioned on the surface of the separation plane. The advantage of the latter solution is, on the one hand, the precision of the realization, but also the time duration, perhaps the shortest of the three for the realization of the design phase.

After carrying out the design part, the semi-moulds will be processed with appropriate image generation programs for the surfaces of each screen that allow the passage only in the exposure area of a light spot with a certain wavelength that will produce the exposure of the resin layer and the production of hardening to the exposed surfaces.

4. CONCLUSION

Advantages of 3D additive manufacturing technology are highlighted by the reduction of material losses semi-finished as well as by using the principal materialization technology by adding material compared to alternative technologies of manufacturing that involves processing by CNC milling with material removal.

However, the sequence of operations that the human operator must go through, regardless of the technology we are discussing, respecting the order of stages such as: CAD design – operation around which all discussions are held regarding the final shape of the finished product, aspects regarding its functionality, the behaviour to the requests to which it will be subjected, the material from which it is to be executed, the technological design - which defines the sequence of operations, processing regimes and processing strategies, etc. available tools and devices.

5. REFERENCES

1. Name, Sure-name., Name, Sure-name., *Title of the book*, 5th edition, Editors eds., City, State, (2009).
2. Moshiri M, Charles A, Elkaseer A, Scholz S, Mohanty S, Tosello G. An Industry 4.0 framework for tooling production using metal additive manufacturing-based first-time-right smart manufacturing system. 2020;93:32–7. 10.1016/j.procir.2020.04.151.
3. RILEY, G.: CLIPS: A Tool for the Development and Delivery of Expert Systems, Proceedings of the Technology 2000 Conference, Washington, DC, 1990.
4. Bear, B., Wolf, A.K., Chasing in the woods, *Forest stories*,Vol.5, No.3, pp. 34 -41, (2009).
5. DUCA, Y.: Bazele teoretice ale prelucrărilor pe maşini unelte, Ed. Didactică şi Pedagogică, Bucureşti, 1969, pp 275-282, (2023)
6. What is 3D Printing / Additive Manufacturing? - https://www.3dsourced.com/guides/what-is-3d-printing-additive-manufacturing/, (2023).
7. Manufacturing Injection Molds www.thomasnet.com, (2023)
8. Masinile CNC si avantajele acestora. TechWood https://www.techwood.ro/articole-si-noutati/web/avantajele-masinilor-cnc, (2023)
9. CNC Machining vs. 3D Printing: Here is What Product Designers Must Know - https://www.china-machining.com/blog/cnc-machining-vs-3d-printing/, (2023)
10. How does MSLA 3D printing work? - https://www.anycubic.com/blogs/3d-printing-guides/sla-vs-msla, (2023)
11. Vasilescu, M.D., Mihai Titu - Comparative study between the generations of 3D printed parts by thermoplastic or optical polymerization, Nonconventional Technologies Review, 2017, 2359-8646, vol.3, 18-23 pag, (2023).
12. Tulcan, A.; Vasilescu, M.D.; Tulcan, L. Comparative Study of the Influence of Bio-Resin Colour on the Dimension, Flatness and Straightness of the Part in the 3D Printing Process. Polymers 2021, 13, 1412. https://doi.org/10.3390/polym13091412
13. Vasilescu, M.D., Influence of technological parameters on the structure and deformation of flat or round parts generated by DLP 3D printing, Nonconventional Technologies Review, Sibiu Vol. 23, Iss. 4, (Dec 2019): 56-61, (2023).
14. Vasilescu, M.D. - Constructive and technological consideration on the generation of gear made by the DLP 3D-printed method, Revista de materiale plastice, 0025/5289, 2/2019, pag. 440-444, WOS: 000476641000030, (2023)
15. Vasilescu, M.D. - Influence of constructive and technological parameters at generated spiral parts with DLP 3D printing process, Revista de materiale plastice, ISSN 0025 / 5289, 4/2019, 56, 801 – 811 pag, (2023).
16. How to Use 3D Printing for Injection Molding - https://formlabs.com/eu/blog/3d-printing-for-injection-molding/, (2023).