# Modeling of the Process of Three-Dimensional Metal Casting

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***Abstract*** **– This paper describes designs of metal castings, produced with the help of 3D technologies. Methods for materials 3D processing are related to the additive method of manufacturing, which is associated with the third industrial revolution, characterized by the resource saving ecological production. The examples of frame cellular castings are shown, which inherit structures of nature with the optimal combination of materials consumption, strength and attractive appearance. The described 3D technologies expand the existing range of metal products. Use of 3D printers reduces the technogenic impact on the environment, saving up to 90 % of the starting material, in contrast to the current "subtractive production". Among the new foundry processes, at the Physico-Technological Institute of Metals and Alloys (Kyiv, Ukraine) there have been patented 3D technologies of sand products molding by means of the deformation of loose materials as well as obtaining sand shell molds for one-time patterns.**

***Keywords*** **– 3D printer, 3D technology, additive manufacturing, castings engineering, cellular castings, computer simulation.**

## I. Introduction

At present, 3D technologies are increasingly often used for foundry processes. In particular, these technologies are widespread for Lost Foam Casting (LFM) in the production of foam patterns at 3D-mills with the help of computer programs [1]. This includes simulations of lattice castings using volumetric prefabricated structures with repetitive unified elements, the foam models of which can be produced at automatic formation machines or 3D-mills [2].

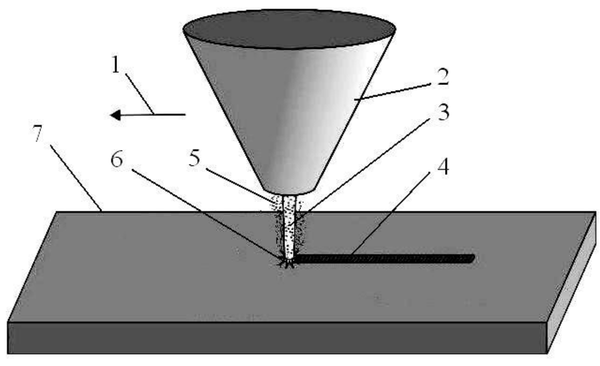
The widespread adoption of 3D printing in the industry is associated with the third industrial revolution, which will differ by the extensive development of additive manufacturing [3]. First of all, use of 3D printers will allow reducing the technogenic impact on the environment, saving up to 90 % of the starting material in contrast to the current "subtractive production" [4]. The latter implies cutting of materials into parts, selection of appropriate elements and their compounds, and that is the basis of the current traditional production. The started third industrial revolution leads to the future world drop in demand for ferrous metals, leaving only competitive resource-saving and environmentally friendly productions [4]. With the spread of the new technology, 3D printing of customized industrial products at the place of their use will reduce the logistics costs as well as the energy consumption [3].

One of the leaders of these innovations is the American car manufacturer Tesla, the head of which is already called the new Henry Ford of the world car industry. Also, NASA recently printed the rocket injector from metal by the laser sintering method, and now it consists of two parts only, instead of the 164 as previously. Foundations of the new industrial paradigm, which includes the additive production, will be created in the next 20 years within the current industrial model [4].

## II. Analysis of the Latest Investigations in Castings 3D Printing

3D printing of metal products includes a number of different processes that are the result of a combination of knowledge from the computer sciences, mechanics, and materials science. The development of most of them began in the mid-90s of the 20th century. Even though they were developed by different institutions, their basic principles are practically identical [5] (see Fig. 1).

As it can be seen from Fig. 1, when moving the nozzle 2 in the direction 1, the beam 3 of the laser rays melts the powder particles 5 in the zone 6, resulting in the deposited layer 4 on the substrate 7. Since details here are obtained from the liquid metal by its melting and layering onto the substrate, where it solidifies, each detail has all the features of the casting. Here, the metal is melted not in the furnace but on the substrate or, less often, in the flow of the heat transfer medium with the solidification and cooling usually in the protective gas and in the presence of most of the phenomena and operations, inherent to the casting and metallurgical processes.




a)

b)

Fig. 1. The method of metal products 3D printing:
a) the schematic diagram [5]:
1 – the direction of motion;
2 – the nozzle of the precipitant;
3 – the beam of the laser rays;
4 – the deposited layer;
5 – the powder particles;
6 - the melt zone;
7 – the substrate;
b) examples of the printed metal products.

The details, obtained in the described manner, under static conditions have the mechanical properties not worse than forging and pressing billets. However, because of the long time of obtaining, they may have a non-uniform macrostructure, which can lead to the fatigue cracks.

At present, the cost of installations for metal products 3D printing, working on computer programs with the simulation of the metal phase transition as well as creation of protective atmosphere, modes of moving, control of the billet dimensions and other similar functions, is estimated as millions of US dollars. This fact often makes their use problematic.

## III. Review of 3D Printed Castings Designs and Their Discussion

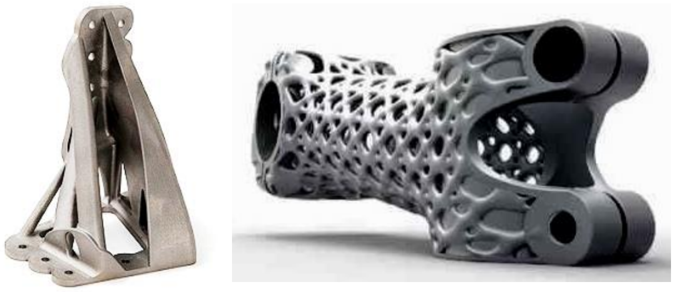
In this review, the appearance of the designs of obtained castings, the gallery of which is constantly replenished from open Internet sources, newsletters, technical journals and exhibitions, is considered.

From the viewpoint of today's traditional casting processes, the most of such metal castings are "masterpieces" of foundry skills. Casters and designers after seeing the new designs, optimized by computer and obtained under its control, will know with what they have to compete. Many designs of 3D castings, obtained without forming equipment, slopes and profits with minimum margins, are optimized by computer programs for searching the configuration with the minimum mass, energy or cost on the whole with fulfilling the requirements of the service assignments.

Thus, in Fig. 2, there are shown the examples of different details of the type of brackets, most of which are mounted in movable constructions. In particular, in Fig. 2, four options of the same detail are presented, and two of them are with the removable inserts, which are used as substrates for the ceiling walls of these details. Fig. 2b demonstrates how the traditional monolithic design is "transforming" into the elegant frame cellular versions. Finally, in Figs 2c and 2d, more options of 3D printed brackets are presented.

a)

b)



c)

d)

Fig. 2. Options for 3D printing of various brackets.

In many cases, a combination of the limiting possibilities of the casting process and optimization of castings designs from the perspective of resource saving leads to the fact that these designs are similar to those observed in living and nonliving nature, including models of structures of organic and inorganic substances.

Obviously, the "solutions" proposed by computer in many respects are approaching the constructions created by nature, which are characterized by a high energy efficiency [2] and also by such specific properties as repeatability of identical elements in different directions, combinatority (fractality), and cellularity.

There exist a considerable number of examples of 3D printing blade details, presented in Fig. 3, which often require high precision in manufacturing of complex blade engraving. Forming metal equipment for traditional casting methods is often more expensive than the single 3D printing of such castings.

The use of principles of the organization, properties, functions and structures of living nature in technical devices is studied by bionics. However, the basis for the design, i.e., creation of the prototype or the inverse image of the supposed or possible object, can be not only images of living and nonliving nature but also some imaginary, ideal, for example, mathematical models, which in the general case do not necessarily have some already found matching anything in the physical world [6].


Fig. 3. Examples of the blade details.

Details from Fig. 4 continue the list of the examples of different designs of 3D cast frame cellular products, and some of them even have a decorative purpose. Optimization of their structure results in the fact that they are in many respects similar to the "technical solutions" borrowed from nature. This is because nature has already "solved" the problems of the conquest of space by constructions with high efficiency and resource saving where living cellular or fractal type constructions have been selected in the course of evolution.

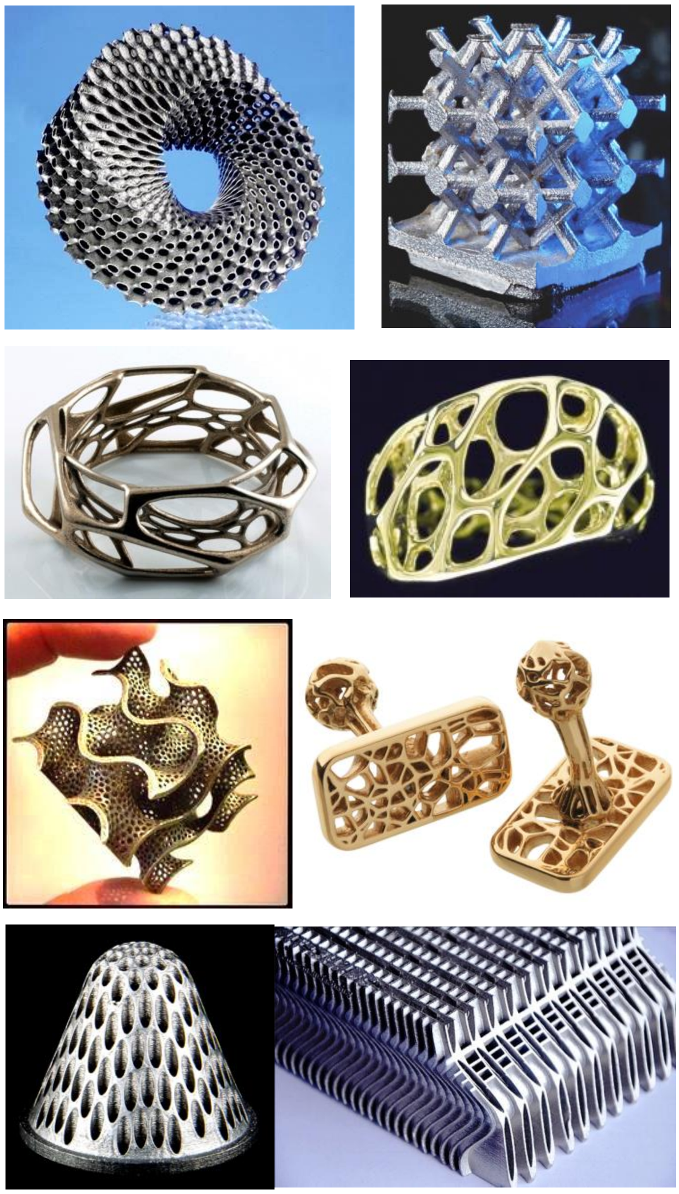


Fig. 4. 3D frame cellular metal products.

Nowadays, the designer arranges "the evolution" of the product right on his/her computer. In this way, the borders are being erased between the scientific and technical levels of knowledge in the reflection of ideas, which probably belong to the "father" of cybernetics N. Wiener and which were presented in his book "Cybernetics: Or Control and Communication in the Animal and the Machine" in 1948.

Today, computer simulation helps not only to reflect our conceptions about the structure of the surrounding world but also to borrow from it some of the details for our own man-made constructions. When we refer to the structure of matter we mean that the basis of our knowledge in chemistry, physics, materials science and most areas of the Earth

Sciences is, first of all, the knowledge about the structure of matter, which largely determines its properties.

Therefore, scientists are aiming to learn how to discover new materials by calculating their structures on the computer [7], whereas constructors put a problem in the same way to design metal constructions, particularly for mechanical engineering [6].

The stable crystal structure is characterized by the lowest energy. Scientists solve the indicated problem by investigating all possible mutual positions of atoms, calculating the energy for each of them and in this way determining the lowest energy and the optimal structure.

This problem cannot be solved directly; however, one can solve it without the exhaustive search, but directing the calculations with the help of self-learning to the "global minimum" of energy.

In that vein, an approach was developed, based on the ideas of evolution, which was a multi-dimensional minimization for the search of any thermodynamically stable states [7]. Creation of the methods of these data analysis led crystallographers to the area of multi-dimensional geometry.

If programs of designing structures of new materials from atoms are created, then, copying atomic lattices analogously to the examples from the work [2], their macro-dimensional analogues in the form of the spatial lattice castings by 3D methods as the development of the methods of cellular metal products casting can be obtained.

Expanding the range of such castings designs, casters develop a new direction of casting of cellular, volume-cellular and skeletal lattice metal products thathave the potential for use as lightweight carriers, reinforcing, insulating, protecting, damping loads spatial constructions, including capable to absorb or pass a flow of matter or energy through their cells.

Examples of 3D castings, freely available on the Internet, are so numerous that it is impossible to discuss all of them in one article.

In order to complement the review, Fig. 5 shows the examplesthat were not included in the previous groups, particularly the art casting, details of small arms, and some case details.

Besides, in the technical literature, there are described castings of nozzles for special purposes and heat exchangers, a variety of jewelry castings, samples of bijouterie, decorative and artistic articles, prosthetic components, including oral and dental, and others.

The considered designs expand our understanding of the possibilities of casting. Some samples at exhibitions are given in the form of examples of the transfer of serial castings, obtained in the sand molds, to 3D casting with "transforming" the traditional monolithic constructions into the elegant frame cellular ones. They are the visual examples of metal-saving and improving the appearance. It is also necessary to mention the ecological aspect of such casting production in the automatic mode in the closed volume of the 3D printer chamber. The absence of casting molds and cores deprives the production process of the release of harmful substances, typical for foundries.


Fig. 5. 3D metal products for different purposes.

Many of the examples from Fig. 4 still look quite fantastic for today's production, although scientists have already described and patented a number of frame cellular castings as well as the original methods of their casting and simulation [2], [6].

Cellular castings can inherit some structures of nature. Also, they can be created by the human imagination, computer-aided design according to mathematical formulas, some visual image or drawing on the computer monitor or according to the given program requirements. Finally, they can be specified by some other conditions, for example, including the method of "augmented reality" [8].

If to watch modern fiction movies with robots, transformers, androids, space ships and stations, machines and weapons, using the engineering point of view, one can find that all these constructions include many castings. Moreover, at present, many of such castings are already available for the production with the help of modern casting processes, including 3D technologies, which greatly expand the existing range of manufactured metal products.

Also, it is necessary to note that among the new casting processes at the Physico-Technological Institute of Metals and Alloys (Kyiv, Ukraine), the technologies of 3D deformation of products from loose materials [9], [10] as well as the method of 3D molding of sand products with getting multilayer shell molds, including the molding according to one-time patterns [11], have been patented.

## IV. Conclusion

The presented review of metal castings, which are examples of materials processing using 3D technologies, illustrates the development of the additive production method. The latter is associated with the third industrial revolution, leading to the resource-saving ecological production. The technological "coil" of this revolution is sometimes ahead of the stages of understanding scientific-practical and research solutions. The described possibilities of 3D processes expand the range of metal constructions, and the shown frame cellular castings often inherit some structures of nature with the optimal combination of materials consumption, strength and attractive appearance. These technologies use scientific knowledge as the basis of technological development. Also, they simultaneously use the tools of computer simulation as a specific method of scientific knowledge, blurring the line between the scientific and technical levels of knowledge by means of science technologization.

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