Българско списание за инженерно проектиране, брой 44, ноември 2021г.

A SHORT REVIEW OF THE 3D PRINTING METHODS USED IN THE AUTOMOTIVE INDUSTRY

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Abstract: Three-dimensional (3D) printing is a novel production technology used mainly in the industry and the leisure sectors, which has proven to be very efficient and reliable, as well as faster and cheaper than some of the traditional production technologies. In the industry it is especially applied for the creation of prototype parts, but its repeatability, precision, utilization of different materials and the variety of available printing methods, have made it suitable for medium scale production in the building, automotive, aeronautical, biotechnology and other sectors. The popular Fused Deposition Modelling (FDM) printing method has made the technology widely available, thus empowering engineers to easily test the functionality of their designs. This article aims namely at briefly reviewing the 3D printing methods used in the automotive industry, by highlighting their advantages and disadvantages, describing their exact applications, and also mentioning real-world examples and projects.

Keywords: 3D printing, automotive, industry, vehicles, additive manufacturing, FDM.

1. INTRODUCTION

Three-dimensional (3D) printing, also known as “additive manufacturing”, or as “rapid prototyping”, is a production technology for creation of three-dimensional objects (also called “prints”) that originated in the 1980s. It utilizes different materials (polymers, metals, ceramics, glass and others) depending on the structure of the used printer and the applied technique (extrusion-based, resin-based, or powder-based). The term “additive manufacturing” emerged due to the main principle of the technology which is adding layer by layer of material in order to achieve the desired shapes of the object. “Rapid prototyping” is linked to the onetime usage of the technology exclusively for prototypes, but it no more appropriate, since the precision, repeatability and cost of conventional 3D printers have made it possible to produce various parts, molds and model replicas [2].

The novel technology of 3D printing has been used in sectors such as industry, building, medicine, leisure, and defense, among many others. Normally, printers vary in prices between 200$ and 500,000$ [16]. An open-source initiative that started in 2005 in the University of Bath called RepRap made it possible for 3D printing to become widely accessible and enter our homes. Thus, nowadays the technology is applied not only for parts and prototypes, but also for leisure and educational models, miniatures and tooling created by DIY enthusiasts. Many universities, libraries and education centers have been equipped with 3D printers for academic and community use. There exist many designs and models freely available on internet platforms that are dedicated exclusively to 3D printing.

Additive manufacturing has become so successful because of its ability to create very complex geometries and structures, even hollow ones. It is currently the technology which guarantees the highest level of customization of produced objects. Moreover, parts’ geometry optimization is a standard practice across the industry – the requirement is to manufacture parts that are robust enough, yet such that consume the least amount of material, thus potentially cheaper. This is possible by removing the material which is not subject to stress. These optimized designs are difficult or impossible to produce without using 3D printing somewhere along the production chain [19]. Additionally, some of the printing techniques are not only a few times faster, but also a few times cheaper than certain conventional production technologies – this enables the adoption of manufacturing on-demand.

The automotive industry in particular is facing challenges every day – there is demand for lighter, safer, faster, and overall better-performing vehicles. This requires for enhancement of the design, manufacturing, supply chain, and logistics of the industry - for this reason, 3D printing has been researched for successful implementation in the industry. The aim of this article is to be as a contribution to the global efforts for promotion of the technology in the automotive sector. Thus, it briefly reviews 3D printing fundamentals and describes and compares the suitable available methods. It also gives examples for the exact application of each of the methods in the automotive industry.

2. 3D PRINTING FUNDAMENTALS

The sequence for creation of an object via additive manufacturing comprises of a few steps – Figure 1. Firstly, the object is modelled in a CAD software, then exported to a suitable format that is readable by the slicing software. The slicing software is responsible for the generation of thousands of cross-sections that define how the object's layers are to be constructed; it also generates the code by which the printing machine is instructed to place these sections. After the object is sliced, its code can be loaded in the printer and the process begins. Once the object is ready, post-treatment processes may be applied in order to better its quality.

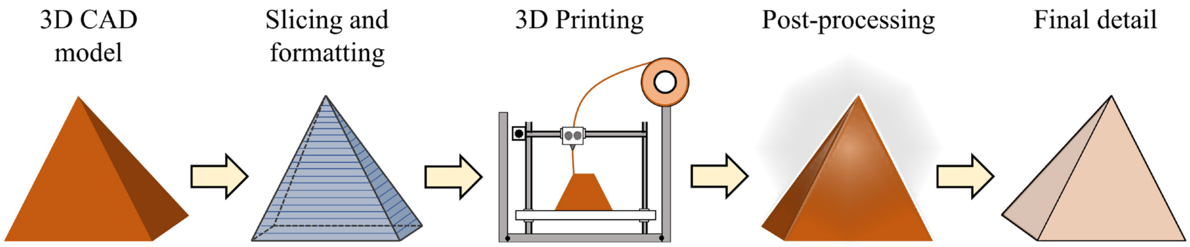

fig. 1. Production sequence for a 3D printed object

Certainly, the slicing software and the 3D printer both have a number of options regarding the speed and temperature of the printing process, as well as layer thickness and geometry of the cross-sections. There are many other options that depend on the printing technique, size of the printing machine, size of the printed object, and type of material, which are managed according to the desired quality of the product. In some of the printing techniques sometimes a compromise between the printing time and the quality of the printed object should be worked out.

Material for the printing, no matter whether extrusion filament cord, resin, or powder, should be continuously fed to the material-dosing head in order for the process to take place. The objects are normally attached to a print bed or a platform which may be able to move in the Z axis in order to free up space for the next layer to be constructed. Good thermal management of the printer and sufficient material are necessary to manufacture an object of satisfying quality.

In comparison to injection molding, additive manufacturing does not require expensive punches, molds and tooling. In comparison to cutting-based machinery, there is less waste material (as much as 40%) and this waste material can be recycled to some extent. In the subtractive technologies as much as 96% of the raw material may be removed in order to create the final item. Additional advantages of 3D printing over these two conventional production technologies are the quick production of initial models and the very low cost of limited production runs [4]. Generally, the current limitations of 3D printing are the low mechanical properties of the products, mostly due to the layered structure of the printed objects; the low material variety of some methods; and the low productivity and high investment cost of some of the methods.

3. 3D PRINTING METHODS AND MATERIALS FOR AUTOMOTIVE PURPOSES

2.1 Extrusion-based

2.1.1. FDM/FFF

Extrusion-based 3D printing is the most common technique for 3D printing. A typical extrusion-based FDM printing machine is shown in Figure 2: **a)** – material is fed in the form of cord through an extruder, a heater and a nozzle – deposition head **b)**, which are fixed on an axis profile with controlled movement by a motor **c)**. The desired object **d)** is printed on the print bed **e)** and in the print area **f)**, layer by layer due to the cooling of the material and the adhesion. The print bed may also be heated. An extrusion-based printing machine resembles to a great extent the multi-axis cutting machines. The construction of the printer may differ depending on the producer's distinct design.

In FDM the raw material moves through Bowden tubes. The tubes are attached via connectors to the extruder and the hot end. The hot end is heated to the melting range of the material and by means of the dosing nozzle the object is built carefully layer by layer. In some FDM printers (cartesian type – Figure 2) the print bed moves in X axis and the deposition head in Y and Z axes, but in other printers the bed moves in the Z axis [1]. Overhang surfaces are printed by means of support structures that are less dense than the actual object which makes them easy to remove – Figure 3.

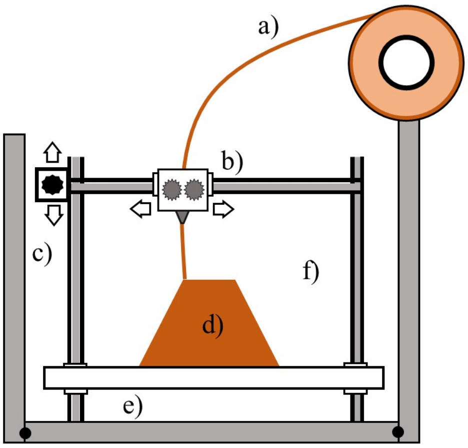

fig.2. Simple schematic of a 3D printer utilizing an extrusion-based technique, figure inspired by [25]

The quality of end surfaces and the mechanical properties of the printed objects strongly depend on factors such as printing temperature, layer height, layer thickness, printing direction, nozzle temperature and diameter, infill, air gap and build styles [9].

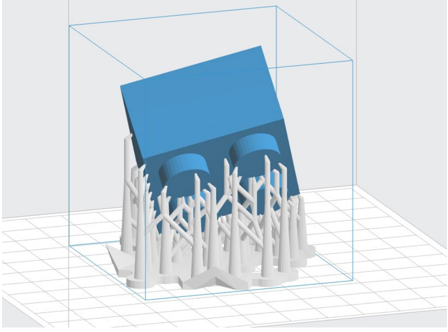

fig.3. A model for 3D printing with supported overhang surfaces [24]

3D printing nozzles are made of stainless steel or brass alloy due to their tight fabrication tolerances and high thermal conductivity [3]. The profiles of an FDM 3D printer are usually made of aluminum, while the housing is plastic. Many times, 3D printed parts are also implemented in the housing of the printer.

Some of the used materials in FDM printing are: PLA, ABS, thermoplastic elastomer (TPE), polyethylene terephthalate (PET), PLA with wood, PLA with metal, and other polymers and polymer composites.

PLA (polylactic acid) is made by corn crops fermentation and is compostable. It is non-toxic, hard, yet brittle and is printed at a wide range of temperatures (170-230 °C). Due to its good properties, it has many applications, including in the automotive industry. ABS (acrylonitrile butadiene styrene) is oil-based and is resistant to impact, wear, high temperatures, and as PLA – has low cost and many applications. ABS can be printed in temperatures ranging 215-250 °C [3]. TPE is a material with great flexibility and may be fed directly to the extruder without a Bowden tube, printed at 180-230 °C for elastic parts and seals. PET is similar to ABS and possesses all its advantages, yet it absorbs moisture easily [1]. FDM can also apply multi-material and multi-color printing by extruding a few materials to a single nozzle or by employing a multi-nozzle design.

Post-processing of FDM-printed objects is not always mandatory, but mostly comprises of laying paintings, coatings, vapor depositions, sanding and polishing. Even though the FDM technique is widely utilized and is very well studied, it has some limitations – processing mostly of polymer-based materials, low rate of production due to low printing speeds, frequent anisotropy defects of the final 3D pieces, long post-processing to achieve desired finish surfaces.

2.2. Resin-based

2.2.1 Stereolithography (SLA)

The resin-based stereolithography 3D printing technique is another cheap and widely accessible technique like the extrusion-based FDM. The basic principle of resin-based 3D printers is illustrated in Figure 4. The device (laser or DLP) **a)** illuminates **b)** a thin layer of a transparent plate **c)** from underneath. This plate is the bottom of a tank full of photopolymerizing resin **d)** which is a raw source material for the already hardened polymerized object **e)**, dragged by the platform **f)**.

Stereolithography is the main resin-based production technique. The polymerization of photosensitive resin is done by means of an UV laser. The resin solidifies when illuminated by the laser and layers are formed one over another as the platform holding the printed object moves. Two mirror galvanometers and a series of mirrors guide the laser to the correct coordinates according to the code of the loaded sliced 3D model. Two approaches exist: a top-down one, shown in Figure 4, and a bottom-up one, where the laser is in the top part of the printer and the platform moves downward. The top-down approach is advantageous and increasingly being applied in contemporary printers as the illuminated surface is always smooth, recoating is not required, and printing times may also be reduced as it is possible to cure full layers of resin at once by projecting two-dimensional patterns onto the transparent plate (DLP – Digital Light Processing). In the bottom-up configuration forces are exerted on the printed object when each cured layer detaches from the tank – the bigger the layer, the bigger the forces [7].

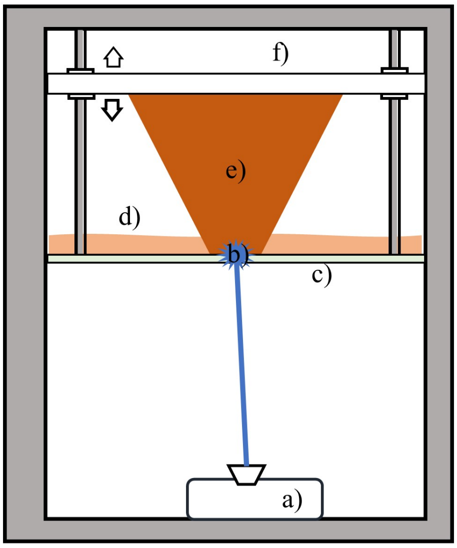

fig. 4. Simple schematic of a 3D printer utilizing a resin-based technique, figure inspired by [26]

It is essential to control layer thickness in stereolithography. The cure depth of a given resin depends on energy of the light to which it is exposed. This energy can be controlled by alternation of different parameters such as power of light source and exposure time. The process requires usage of supporting structures just like in extrusion-based printing – Figure 3. Mainly, the technique is applied for small objects with high surface detail needed for prototyping, or it can also be used for making of molds. It guarantees faster printing time than FDM and smooth surface finish. Post-processing includes additional curing, washing and drying.

There are few commercially-available resin types to be used in stereolithography. These resins are based on multi-functional monomers with low molecular weight that are mostly rigid and glassy, yet brittle. There also exist resin types with high molecular weight employed for creating of elastic parts. Ceramic powder may be included in the resin to a maximum rate of 53% wt in order to print composite objects. The powder particle needs to be smaller than the layer thickness and the resin's viscosity should be well-managed to achieve successful prints. Such composite objects are stronger than polymer-based ones [7].

New types of resins are being developed constantly to enable creation of SLA-printed objects with different properties. Unlike FDM printing though, for SLA it is hardly possible to perform multi-material printing. Another challenge for SLA may be the removal of uncured resin as some of types resins are toxic. Moreover, SLA printers tend to cost more than FDM ones from the same class and size.

Two variations of SLA are Digital Light Processing (DLP) and Liquid Crystal Display (LCD) 3D printing. DLP projects full pixel-patterned light images for each layer, thus curing the layer at once. The light is reflected on a Digital Micromirror Device (DMD) which directs it to the transparent bottom of the resin tank. Because of the digital screen used, the images comprise of square pixels, thus each layer is made out of voxels [17]. The resolution depends on the projector as it sets the number of pixels the image has, making it less scalable than SLA, so most DLP printers are optimized for specific print sizes and objects. DLP is faster when printing larger parts and larger build volumes due to its working principle.

LCD 3D printing is similar to DLP but it flashes the complete UV layers through an LCD directly onto the print area. The light is not expanded; therefore, pixel distortion is less common than in DLP. The printing quality depends on the number of pixels the display has, and likewise to DLP, printing times are shorter for larger items and larger volumes in comparison to SLA. For all three printer types good calibration must be achieved for satisfying quality. In general, DLP printers tend to have the highest prices [21].

Another interesting resin-based technology that is somewhat similar to FDM is Polyjet printing. Polyjet also utilizes polymeric resin like SLA, DLP and LCD printers, but the material is deposited (jetted) directly onto the print bed by an array of small nozzles and is cured immediately after by the UV lamps that are housed in the deposition head. This technique is certainly faster than SLA, it is easier to manage multi-color and multi-material printing with it, it requires less post-processing, and the need for managing of a tank, full of potentially toxic resin, is eliminated. However, Polyjet is significantly more expensive than SLA.

2.3. Powder-based

This approach comprises of selective curing of powder to form the layers of the printed object. A simple schematic of the technique is presented in Figure 5. A moving deposition head **a)** creates the layers of the object **b)** by dropping glue/binder or by laser sintering of the powder bed **c)**. Once a given layer is ready, the platform **d)** moves down, freeing space for the leveling mechanism **e)** to distribute new uncured powder from the powder reservoir **f)** to the powder bed. The printed item rests in the unfused material and so overhang surfaces and thin walls are supported without auxiliary constructions like the ones used in the extrusion-based and resin-based techniques, which enables the manufacturing of very complex structures. Only fully closed yet hollow objects are not attainable with the technique since the unused powder inside the object needs to be extracted.

2.3.1 Selective laser sintering (SLS)

SLS, or also known as Direct Metal Laser Sintering – DMLS in cases when the applied material is metallic, utilizes a laser to selectively sinter patterns in each successive powder layer. The process has three stages: a) warm-up, during which the powder is heated to the processing temperature, b) build phase, in which the desired CAD object is created, and c) cool down, where the powder is cooled to ambient temperature [5]. The processing temperature is close to the melting temperature of the material in order for the laser to easily reach the melting point of the material. The narrower the temperature melting zone is, the closer the operating temperature can be maintained near it without risk of curing all the material which allows the laser to sinter fast and efficiently [8].

Qualitive sintering is obtainable by employing pure powders with isotropic structure. Powder particles with the best layering options are those that have spherical form and a diameter accounting to approximately half of the layer's thickness. The layer thickness is dependent on the diameter of the laser beam.

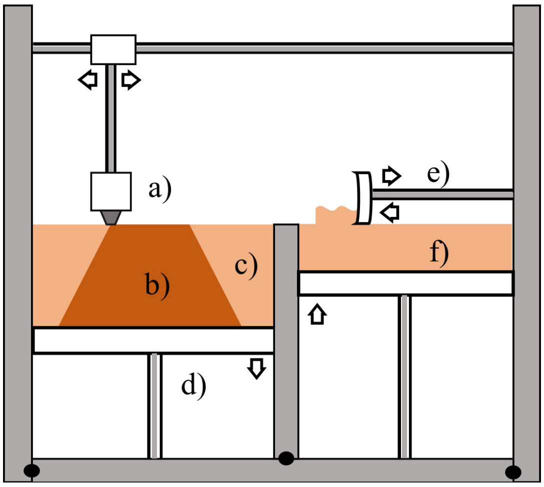

fig. 5. Simple schematic of a 3D printer utilizing a powder-based technique, figure inspired by [27].

SLS uses many different materials – polymers (PA – polyamides, PLA, PET, PVA – Poly Vinyl Alcohol, TPE, and others, including their composites) and metallic materials (stainless steels, aluminum, titanium, precious metals, Inconel, and others). DMLS is mostly applied for higher volume productions of smaller parts and also for single big objects when laser metal deposition (LMD) cannot be used (discussed later in the article). The most common and easiest material for 3D sintering is Polyamide-12 [5].

SLS and DMLS produce objects free from residual stresses and internal defects. DMLS can not only produce prints of close quality to such made by traditional production technologies like forging and casting, but it can also assure shorter production times for prototype parts, less tooling and fewer post-processing operations. Generally, SLS prints have complicate structures with good mechanical properties and good chemical resistance. They can also be dyed to almost any color.

There are, nonetheless, a few downsides of the selected techniques: the porous end-surfaces that need finishing; the possible anisotropy of the layers common for all 3D printing techniques; the present high price of commercial printers; not all of the unused powder is recyclable.

2.3.2 Multi Jet Fusion (MJF)

MJF also extensively applies Polyamid-12 and other polymers, but the working principle is slightly different in comparison to SLS. A fusing agent and a detailing agent are applied over the powder via a deposition head much like in inkjet printing, then another head exposes the powder bed to UV light. The powder soaked with fusing agent melts under the light, while the areas with detailing agent remain loose in order to define the exact borders of the object for dimensional accuracy [18, 28].

MJF guarantees higher density and lower porosity of the produced parts than SLS. Better surface finish, less post-processing and higher productivity is also evident. Additionally, as much as 80% of the powder material for each printing process may be recycled. However, MJF has less material and color variety than SLS and is still relatively expensive.

Binder jetting is a similar method to MJF which only applies a binder agent without irradiating the powder bed with a laser or a light beam. It uses metals, polymers and ceramics, has the same productivity as MJF, and can print objects in full color. This technique is particularly good for creation of sand molds. The method is not suitable for structural parts due to the use of binder agent. Post-processing (furnace sintering and finishing) is required. The cost, likewise to SLS and MJF, is still high.

2.4. Other types/hybrids

2.4.1. Laser metal deposition (LMD)

LMD, also referred to as directed-energy deposition, is one of the main types of additive manufacturing that employs metallic materials. It guarantees almost no waste material, short production times, and energy savings. The method applies a high-power laser beam which fuses layers of metal. LMD could be classified as both extrusion-based and powder-based since the material is supplied to the deposition head (nozzle) over a metal substrate in the form of wire or powder – Figure. 6. The deposition head movement is accomplished by a multi-axis robot.

The material **a)** is fed through manifolds in the deposition head directly onto a surface **b)** where the laser beam **c)** generates a molten pool **d)**. This allows for good adhesion of the layers **e)** as the liquid metal is held by the already hardened metal layers through surface tension in the fusion zone **f)**, thus, material deposition in every wanted direction is feasible. The laser beam is typically focused by lenses at a single spot, travelling through the center of the deposition head. The process often utilizes inert gas **g)** sprayed at the molten pool in order to protect the created object from oxidation [6].

The process is applicable for both the creation of new items, and for repairing and coating of existing ones, mostly for industrial purposes. It supports stainless steel, aluminum, copper, titanium, Inconel (nickel-chromium-based superalloy) and even ceramics [1]. An extension of LMD is Electron Beam Melting (EBM) which is very similar but uses an electron beam rather than laser for the melting of the powder. EBM uses primarily titanium alloys for production of parts for the aerospace industry.

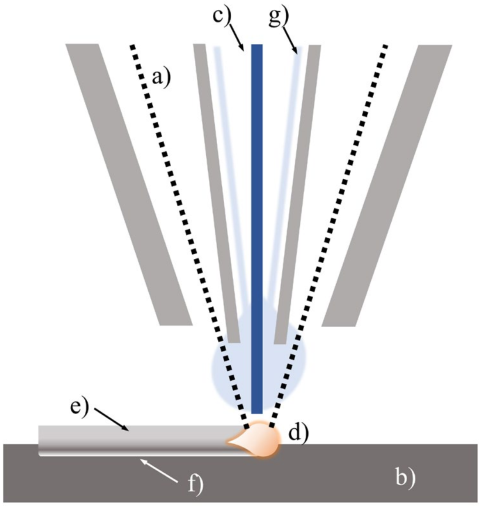

fig. 6. Simple schematic of the LMD working principle.

This production method has several limitations – poor finish surfaces that require post-treatment; low resolution since the layer thickness is dependent on the diameter of the laser beam; possible anisotropy and deviation from the set layer dimensions due to the distinctive cooling of each of the layers. In terms of the physical form of the fed material, powder LMD is a more refined and controlled process in comparison to wire LMD, by guaranteeing better deposition rates, and promoting good properties of the final prints. It also enables robotic control and powder can easily be continuously supplied. On the other hand, wire LMD is cheaper, with lower equipment complexity, nearly 100% material usage efficiency and is generally less toxic than powder LMD [6]. In Table 1 are presented the general advantages and disadvantages of the selected 3D printing methods.

Table 1. Advantages and disadvantages of the selected 3D printing methods used in the automotive industry.

Method	**Materials**	**Advantages**	**Disadvantages**
FDM	PLA, ABS, PET, TPE, other polymers, polymer matrix composites.	• Low initial investment cost and low cost of materials. • Good surface finish, may not require post-processing. • Widely accessible, modular printer designs with high flexibility.	• Support structures required. • Long printing times, low productivity. • Worse quality than SLA and SLS.
SLA	Polymeric photosensitive resins; resin matrix composites.	• Low initial investment cost for some printer models. • High accuracy with very good surface finish, high thermal durability of printed parts.	• Support structures required. • Handling of toxic resin, ventilation required. • Long printing times, low productivity, requires post-processing such as washing and curing. • Low variety of available materials and complex for multi-color printing.
LCD/DLP	Identical to SLA.	• Low initial investment cost for some printer models. • High accuracy with very good surface finish, high thermal durability of printed parts. • Relatively short printing times with good productivity.	• Support structures required. • Handling of toxic resin, ventilation required. • Low variety of available materials and complex for multi-color printing. • Less scalable than SLA.
Polyjet	Identical to SLA.	• High accuracy with very good surface finish, high thermal durability of printed parts. • Short printing times with good productivity. Printing in full color. • Less post-processing and more scalable than SLA/DLP/LCD.	• Support structures required. • Handling of toxic resin, ventilation required. • Low variety of available materials and also more costly investment than SLA/DLP/LCD.
SLS/DMLS	PLA, PA, PET, PVA, TPE, other polymers and their composites; stainless steels, aluminum, titanium, precious metals, cobalt and nickel alloys.	• Good accuracy and good chemical resistance of produced objects. Good productivity. • Can produce very complex objects and has a variety of materials. • No support structures required.	• Expensive initial investment and expensive powder. • Requires post-processing. Porous surfaces that need finishing.
MJF	Polyamid-12 and a few other polymers.	• Better accuracy and surface quality than SLS, very good productivity, less post-processing than SLS. • Can produce very complex objects, up to 80% of the unfused powder can be recycled, no support structures.	• Expensive initial investment and expensive powder. • Handling of agents additional to powder material. • Structurally weaker objects than SLS.
Binder jetting	Polymers, iron, stainless steel, ceramics, sand.	• Better accuracy and surface quality than SLS, very good productivity. • Can print well ceramics and sand for molds.	• Identical to MJF.
LMD/EBM	Stainless steel, aluminum, copper, titanium, Inconel, ceramics.	• No support structures required. • Can be used for repairs of existing objects. • Denser parts than DMLS.	• Expensive initial investment and expensive powder. • Requires post-processing. Poor resolution and surface finish. • Low material variety and lower productivity than SLS.

3. APPLICATIONS

3.1. Educational models, prototypes, replicas, molds

Desktop-based FDM and SLA printers easily produce detailed models and scaled replicas for educational purposes at very low cost for reasonably short times. Models of given aerodynamical components or whole scaled racing cars for measurements of the drag coefficient in wind tunnels are very common – Figure 7 a). Production of RC vehicles, as well as powertrain, gearbox and suspension models, is also feasible with the same techniques of 3D printing – Figure 7 b).

Design validation by making prototypes of future massively produced parts is achievable via all the mentioned methods depending on the structure complexity, material type and the required surface finish.

3.2. Sand casting molds, molds for carbon fiber parts

Binder jetting is very convenient and brings new designs for sand molds for casting due to the possibility to print 3D modelled molds – Figure 7 c). Parts of molds that are later built into a single advanced one can also be produced easily guaranteeing complex casted prototypes. The molds produced by binder jetting potentially have better properties than those produced by traditional methods [10]. FDM and SLA printing, on the other hand, are very cheap and convenient for production of small molds intended for making of fiber carbon parts used in the automotive industry [14].

3.3. Standard parts, customized parts, tooling, whole vehicles

Individual parts can be produced via additive manufacturing techniques. Koenigsegg applies it for some of the parts of its supercars such as the turbocharger, Porsche prints seats, while Rolls Royce – brackets; brake discs have been created by Ford, brake calipers by Bugatti – all these parts are printable by the two techniques employing metallic materials – DMLS and LMD [11] – Figure 7 c). Additive manufacturing can potentially be a great possibility for automotive OEMs to enhance not only their design and manufacturing, but also the supply chains by outsourcing the production of specific parts to small manufacturers with 3D printing stations for fast production on-demand. Other good niches for additive manufacturing technologies concerning the automotive industry are production of customized driver-specific parts, such as seats and steering wheels, and production of discontinued parts for older vehicle models.

fig. 7. Example of 3D printed objects: a) – FDM RC F1 racing car [13]; b) FDM and SLA-printed scaled replica of an internal combustion engine [15]; c) sand mold made by binder jetting and the metal object created by sand casting using the same mold; the same metal part can also be produced by using SLS or LMD [23]; d) autonomous electric shuttle "Olli" with 80% of the parts and components being 3D printed [20].

Moreover, complete vehicles can also be created using additive manufacturing – the autonomous shuttle "Olli" by Local Motors is a real-world example, with 80% of the parts being 3D printed and 100 % recyclability with its main structure being created by the largest commercial FDM printers in the world as of 2020. "Olli" has a modular build block construction with 90% fewer parts than a traditional vehicle that can be customized and greatly lowers the energy consumption during production. The used material is a composite polymer and it takes around 9 hours to print the chassis of Olli [22].

Volkswagen are also exploring the options of 3D printing – in one of their factories - Autoeuropa, in-house production and usage of 3D FDM-printed jigs, tools and fixtures has been implemented, as the company claims enormous saving in time and cost in comparison to the traditional sourcing [12].

4. CONCLUSION

Three-dimensional printing has been rapidly developing and has the potential to become one of the main production technologies for the industry. In the automotive sector alone are applied more than five different additive manufacturing techniques for the fast and efficient production. More precisely, all the mentioned technologies can be applied for automotive prototypes and polymeric tooling, and parts in cases when non-metallic materials are used, while DMLS and LMD are suitable exclusively for metallic parts and prototypes. Polymer and metal molds are also producible with most methods, depending on the material, but binder jetting is particularly good for sand molds. Molds for production of big carbon fiber parts and for whole chassis sections can be easily and cheaply printed via FDM.

Many automotive companies are exploring the possibilities that 3D printing has offer and have already enhanced their portfolio with advanced designs whose production is the most feasible namely when applying this technology. Moreover, additive manufacturing is fast and cheap for prototyping, and presents a satisfactory variety of workable materials given the requirements of the automotive industry. It has the potential to decrease production times and costs, reduce the dependency of OEMs on external suppliers, and enable the creation of mass customization production.

Nonetheless, 3D printing still lacks the maturity and power of traditional production technologies:

- It has low productivity in terms of mid to large-scale high-volume production.
- The properties of produced objects are somewhat lower due to the presence of layers in the construction - anisotropy and slight deviations from the dimensions are possible.
- Some of the 3D printing techniques still require very high capital investments.

Even given these disadvantages, the outlooks for the technology are very positive, and it is expected to rapidly develop during Industry 4.0, by enhancing the used techniques for faster and larger productions and by applying new materials, thus becoming more sustainable and more competitive to traditional production technologies.

Acknowledgement

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