ADDITIVE MANUFACTURE. APPLICATIONS IN THE PETROLEUM AND PETROCHEMICAL INDUSTRY

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ABSTRACT

In the current stage of technology development, there are more and more important changes related to the development of existing manufacturing technologies and the emergence of new technologies. The paper analyses the current state of development of additive manufacturing technologies, with possible applications in the oil industry. This new type of technology has transformed, in the short term, and will revolutionize, in the long term, the production methods, in any field of work.

Keywords*:* additive manufacturing, 3D printing, CAD

INTRODUCTION

With the increasing complexity of industrial products, environmental protection requirements and resource conservation, new manufacturing technologies are needed.

3D printing or additive manufacturing (AM) is a process of making three-dimensional bodies by adding material layer by layer. Physical objects are made using the data of a digital model, a 3D model, or other sources such as an AMF (Additive Manufacturing File) [8].

In this context, 3D printing is a relatively new part manufacturing technology, usually with a complex configuration. The working technology consists of a process of forming a three-dimensional solid body, made by a repetitive process of adding successive layers of material, in different forms [1-6].

This technique of manufacturing three-dimensional solid objects by adding the material layer by layer, is done through a robotic system of additive manufacturing - 3D printer. The materials that are deposited with the help of the 3D printer are plastics, resins, metal powders, etc. [6].

Additive manufacturing (AM) [7] is seen as a key technology for "Industry 4.0". It is designed to combine the advantages of mass production and manufacturing and even to generate individual parts economically on an industrial scale. AM machines can also create components of high complexity, which cannot be executed using conventional technologies. AM machines use principles similar to those used by 3D printers. The piece is projected on a computer; subsequently, this model is transferred to the system, where a heating module or a laser melts the plastic. With this molten material, the system generates the projected part, layer by layer. Compared to 3D printers for private use, AM systems are much more efficient. They can, for example, process plastics, metals, ceramics, etc., usually use laser technology and work with great precision and more complex CAD models [7].

In this context, laser beam powder welding has been improved to allow more materials to be used in additive manufacturing. Through this procedure, a system feeds the processing area with various powders. The laser melts the powder and deposits it on the surface of the part. As a result, the part is generated layer by layer, and the process can be adapted to the requirements of high-performance materials [7]. It is also possible to print nickel-based alloys that are difficult to weld using traditional methods. However, the technology only works if the temperature, dust, feed rate and other parameters are set correctly [7].

ADDITIVE MANUFACTURING PROCEDURES

The best known types of additive manufacturing processes are [4, 5]:

- Stereolithography (SLA);

- Fused deposition modelling (FDM);

- Manufacture of laminated parts from laminated sheets (LOM);

- Selective laser sintering (SLS);

- Selective Laser Melting (SLM).

Stereolitography (SLA) [5, 9, 10]

Stereolithography (SLA or SL) is a rapid prototyping technology, widely used in the industrial environment, for the production of molds, models and even functional components. Also known as photo-solidification or optical fabrication, stereolithography involves the use of an ultraviolet laser beam to solidify a liquid photopolymer resin in the printer's construction tank. Under the action of ultraviolet laser light, this curable resin (sensitive to ultraviolet light) solidifies in successive layers, thus obtaining the solid 3D model. The principle of printing by the SLA manufacturing process is shown in Figure 1, [10].

The desired 3D model is initially divided into cross sections, which the laser beam traces on the surface of the liquid resin. Exposure to ultraviolet laser light solidifies the pattern drawn on the liquid resin, resulting in a solid constructed layer (3D printing), which is added to the previous layer made (figure 2) [10].

The advantages of the SLA manufacturing process are [10]:

• SLA is one of the most accurate 3D printing techniques on the market.

• Prototypes can be created with extremely high quality, with finely detailed features (thin walls, sharp corners, etc.) and complex geometric shapes.

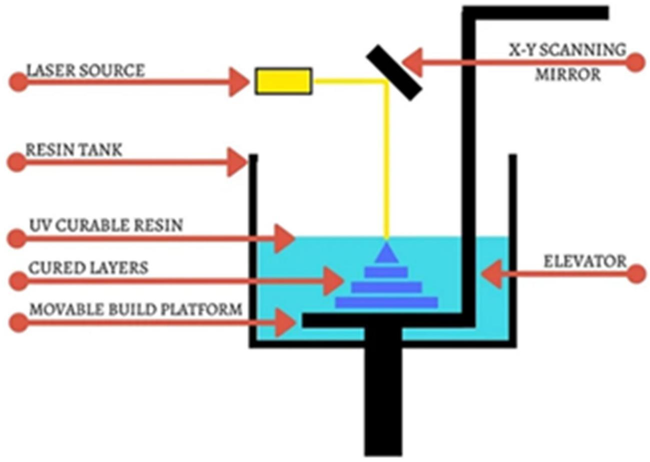


Figure 1. Principle of SLA printing technique [10]

• SLA offers the tightest dimensional tolerances of any additive manufacturing technology: +/- 0.005 ″ (0.127 mm) for the first inch and an additional 0.002 ″ for each additional inch.

• Print surfaces are smooth.

• Construction volumes can reach 50 x 50 x 60 cm³ without influencing accuracy.

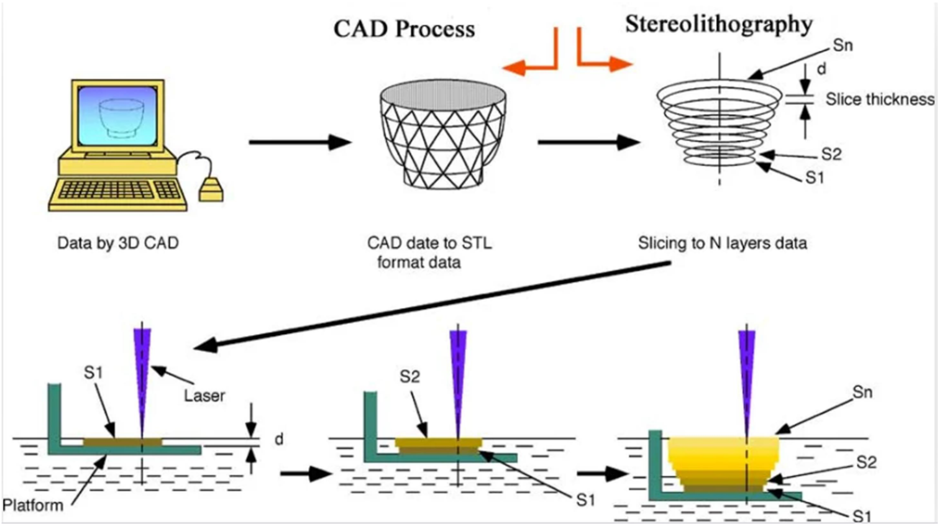


Figure 2. The link between the 3D model and the principle of the SLA printing technique [10]

The disadvantages of the SLA manufacturing process are [10]:

• The manufacturing process takes a long time.

• Resins are relatively fragile and therefore not suitable for functional prototyping or mechanical testing.

• SLA offers limited materials and a limited range of colors.

• SLA printing costs are relatively high.

Fused deposition modelling (FDM) [11, 12]

FDM is an additive manufacturing technique widely used for modelling thermoplastics (plastics) [12].

Other names used for this manufacturing process [5] are: MEM (Melting Extrusion Modelling), thermoplastic extrusion TPE (Thermoplastic Extrusion), FFF (Fused Filament Fabrication).

Materials used can be [12]: ABS (acrylonitrile butadiene styrene copolimer), PLA (polylactic acid), PVA (soluble), PC (polycarbonate), polyethylene HDPE, polypropylene, elastomer, polyphenylsulfone (PPSU) and ULTEM Polyphenylsulfone (PPSF), polyamide, casting wax.

Figure 3 schematically shows the phases of the FDM additive manufacturing process [12].

FDM / FFF can also be used for printing ceramic materials. In this case, the thermoplastic material is filled with a large amount of ceramic powder. This raw material obtained is molded into a tube with a constant diameter (usually 1.75 or 2.8 mm). After the printing process (figure 3), the manufactured parts are burned and the ceramic powder is subsequently sintered in a dense ceramic [12].

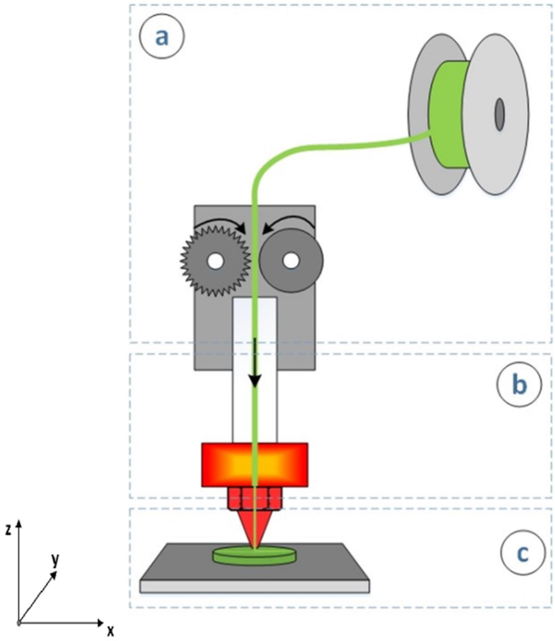


Figure 3. Schematic representation of the phases of the FDM additive manufacturing process [12]: a - the thermoplastic wire is inserted into the extrusion head by feeding the rollers, b - the polymer is melted and extruded through a nozzle; c - the extruded molten material is deposited layer by layer

However, FDM / FFF is a technique for modelling thermoplastic ceramics (Figure 4) and therefore the potential polymers are similar to those used for thermoplastic pressing, extrusion and injection molding [12].

Compared to polymeric materials, the process of modelling ceramics is more difficult due to the loading of solid ceramic particles inside the thermoplastic. In this context, it is essential to control the rheological properties of polymeric-ceramic powder compounds and the effect of organic additives on the printing processing stage [12].

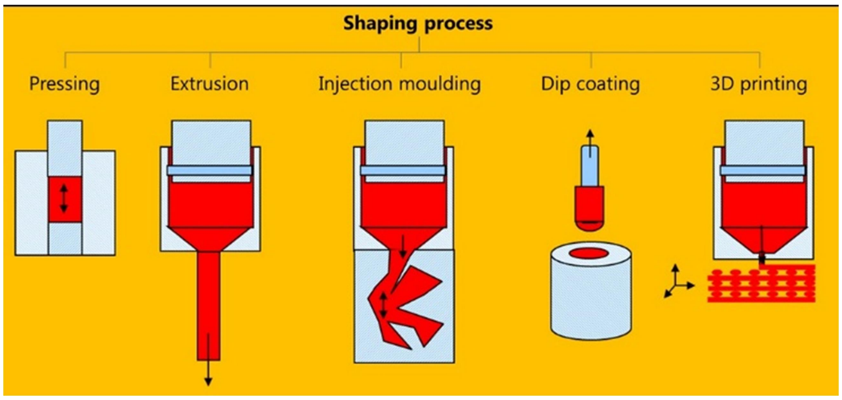


Figure 4. General presentation of different thermoplastic modelling processing techniques for ceramic materials [12]

Fused deposition modelling (FDM) has been successfully used for the manufacture of various ceramic materials such as lead zirconate titanate (PZT), tricalcium phosphate (TCP), alumina [12].

Layered object manufacturing (LOM) UC ultrasonic consolidation is a rapid prototyping system in which layers of paper coated with adhesive, plastic or metal laminates are successively glued together and cut into the desired shape using a knife blade or a laser (Figure 5, [13]).

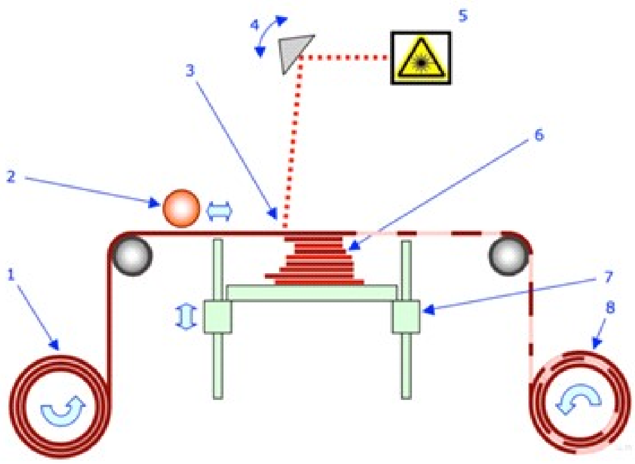


Figure 5. Manufacture of laminated parts [13]: 1 – foil supply; 2 - heated roller; 3 - laser beam; 4 - scanning prism; 5 - laser unit; 6 - layers; 7 - moving platform; 8 - waste

The parts are made by stacking, gluing and cutting layers of adhesive-coated material on top of the previous one. The laser cuts the contour, and the process is repeated until the part is completed. After a layer is cut, the additional material remains in place to support the part during construction. The main disadvantage of the LOM technique is the small variety of materials that can be used in manufacturing, but it has the advantage of very good resolution and also the ability to print in very different colors. The main applications in which LOM can be used are: testing the shape of physical models, printing color parts, making large 3D models at a relatively low price compared to other printing methods [9].

Selective laser sintering (SLS) [9, 14]

The basic concept of SLS is similar to that of SLA. Uses a moving laser beam to selectively track and sinter the polymer powder and / or metal composites into successive cross sections. The pieces are built on a platform that is adjusted in height equal to the thickness of the built layer (figure 6). The additional powder is deposited on top of each solidified and sintered layer. This powder is rolled on the platform from a container before the layer is built. The powder is kept at a high temperature so that it melts easily upon exposure to the laser. Unlike SLA, no special support structures are required, as the excess powder in each layer acts as a support for the built part. With the metal composite material, the SLS process solidifies a polymeric binder material around the steel powder (diameter 100 microns) one layer at a time, forming the part. The part is then placed in an oven at temperatures above 900° C, where the polymeric binder is burned and the part is infiltrated with bronze to improve its density. Burning and infiltration procedures usually take about 24 hours, after which secondary processing and finishing are carried out. Recent improvements in accuracy and resolution, as well as reduced steps, have minimized the need for secondary processing and finishing.

SLS allows the use of a wide range of materials, including nylon, nylon filled with glass, SOMOS (rubber).

Selective Laser Melting (SLM) [15, 16, 17].

Newer additive manufacturing processes include Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM), Inkjet Technologies, FDM (Fused Deposition Modelling).

Selective laser melting (SLM), also known as direct laser metal melting (DMLM) or laser powder fusion (LPBF), is a rapid prototyping, 3D printing or additive manufacturing (AM) technique designed for use a high-density laser to melt and fuse metal powders together [16]. The SLM process is considered to be a subcategory of selective laser sintering (SLS). The major difference is the type of raw material or powder it uses. While SLS mainly uses nylon polymeric (PA) materials, SLM uses only metals. The SLM process has the ability to completely melt the metallic material [17]. For both SLM and SLS manufacturing processes, the basic process is the same. Figure 7 shows the scheme of selective laser melting [17]. A similar process is the electron beam melting (EBM), which uses an electron beam as an energy source [16]. SLM is one of the most interesting 3D printing technologies available today and is used for both rapid prototyping and mass production. The range of metal alloys available is quite extensive. The final product has properties equivalent to those manufactured by traditional manufacturing processes [17]. SLM manufacturing technology is used to manufacture parts for a variety of industries, including the aerospace, dental, medical, oil industries. The dimensions of the executed pieces are small to medium, the geometric shape being complex. The technology is also very cost-effective and time efficient. The technology is used both for rapid prototyping, as it reduces the lead time for new products, and in current production as a cost-saving method by simplifying complex assemblies and geometries [16].

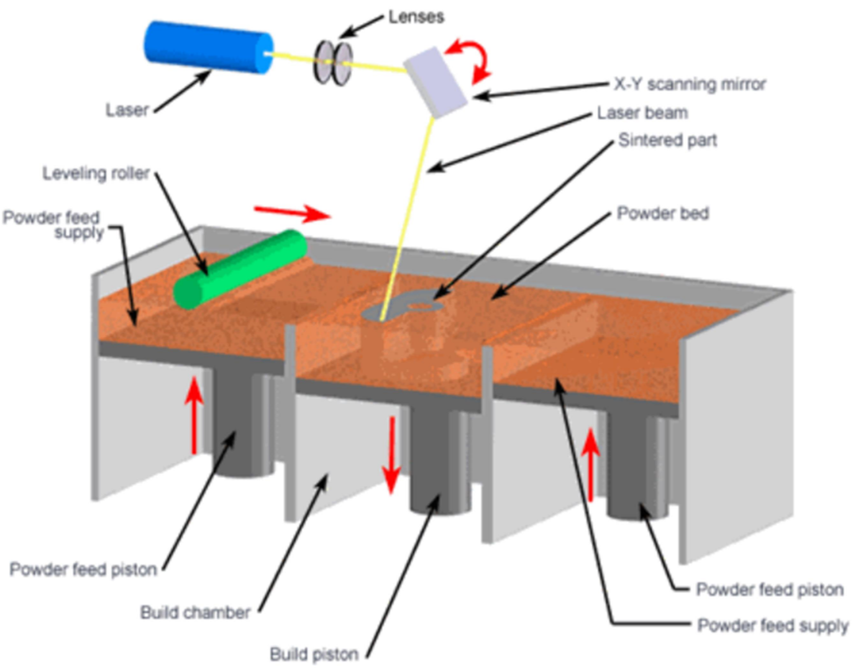


Figure 6. Selective laser sintering (SLS) [14]

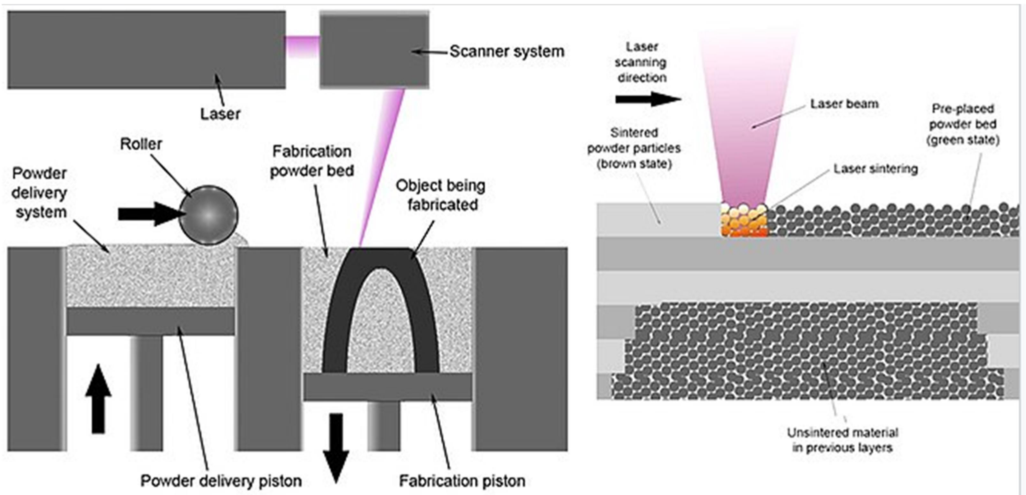


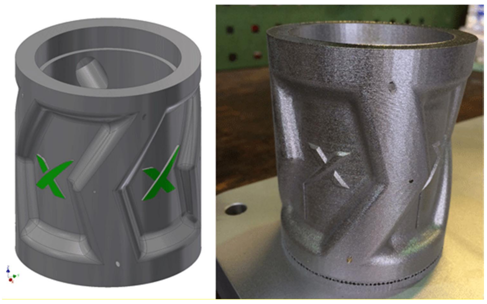
Figure 7. Selective laser melting scheme [17]

APPLICATIONS IN THE PETROLEUM AND PETROCHEMICAL INDUSTRY

The oil and petrochemical industry covers a wide range of activities, from field exploration to drilling, extraction, refining and distribution of products. All these activities involve certain requirements, related to safety conditions, pollution, environment, etc. In this context, companies in the oil and petrochemical equipment manufacturing sector try to propose appropriate solutions to meet the specific standards of quality, reliability and durability, in the conditions of a manufacture with the lowest possible costs. The answer to these requirements can be given by the use of additive manufacturing (AM). The ability to produce complex components that would be impossible to achieve through the use of traditional manufacturing processes makes 3D printing an essential technology [18, 22, 23, 24].

The use of AM for the production of equipment in the oil and petrochemical industry has so far been done with caution due to the difficult operating conditions in this industry.

The Norwegian company EnergyX uses AM to produce a nozzle designed for the cleaning of oil and gas wells (Figures 8 and 9), becoming the first company in this sector to use AM technology [19].



a *b*

Figure 8. Nozzle [19]: a - CAD model; b - the printed part before being cut from the construction plate

Figure 9. Assembled nozzle [19]

Tests on the manufacture of AM were performed initially using plastics and then in the final manufacturing phase of Inconel 718 [19].

Tru-Marine Pte Ltd, which performs repairs, overhauls, maintenance and spare consumables for turbochargers in marine, offshore, power and locomotive applications, applies Laser Aided Additive Manufacturing (LAAM) technology to repair turbocharger components (Figure 10). A robotic LAAM system was developed and the appropriate training of staff was made [20].

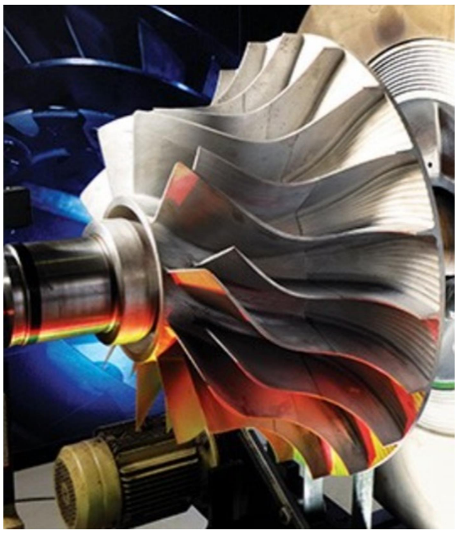


Figure10. Turbocharger Repair - LAAM Technology [20]

Prior to the implementation of the LAAM process at Tru-Marine, most of the repairs were performed manually using the TIG procedure. Through manual repair processes, productivity and quality are dependent on the experience and skills of the individual operator. For example, a part needs four days to be repaired by manual TIG welding. With the LAAM process, the repair can be done in two hours. Surface quality and dimensional accuracy are much better, thanks to the easy-to-control process [20].

Equipment and machinery in the oil industry are generally hydraulically and / or pneumatically operated. Additive manufacturing of hydraulic parts, such as hydraulic blocks (adapter blocks), is an alternative to traditional manufacturing methods, such as mechanical processing and casting [21]. The traditional production of hydraulic blocks causes very high processing costs; it starts from a block of steel that is machined through milling and drilling operations to create internal oil channels [21]. The additive manufacturing process and technology allow a completely free design of the geometry without the risk of overlapping the hole (Figure 11).

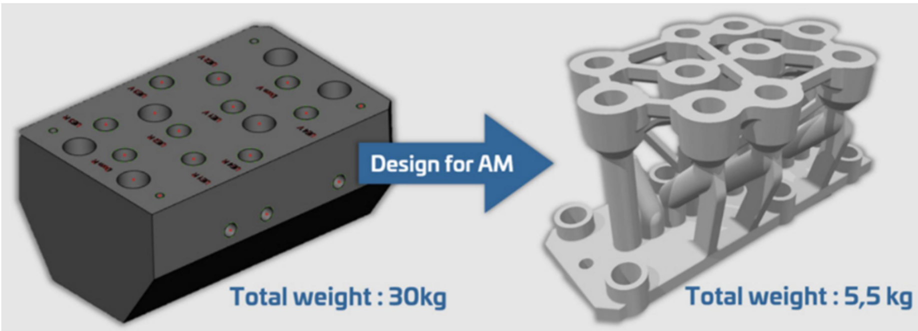
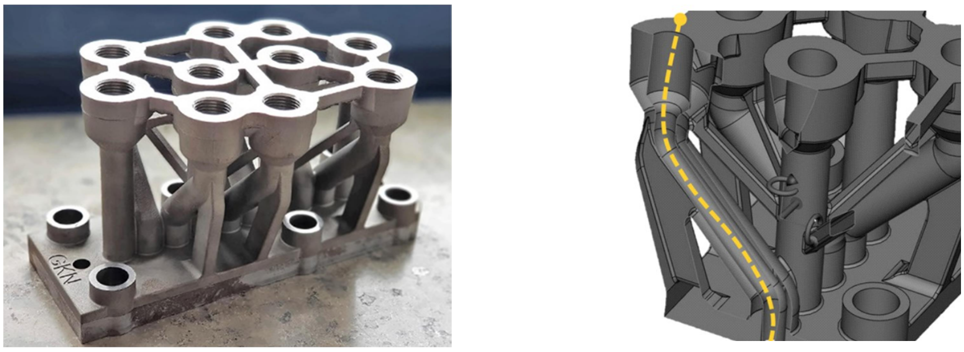


Figure 11. Modelling of hydraulic blocks [21]

The hydraulic blocks produced by AM are considerably lighter and can be adapted to the requirements (Figure 12). An important range of products is fittings, centrifugal pump rotors, etc. (Figure 13). Manufacturing these parts using traditional technologies involves time consuming and expensive operations.



a *b*

Figure 12. Hydraulic block [21]:a - part obtained by AM; b - optimized flow channels

In the oil and gas industry, working conditions require the equipment used to continuously improve quality and durability. Severe environmental conditions (aggressive working environment) require the use of expensive materials. For example, for the drilling rig, the severe operating conditions led to the use of new construction variants, made by additive technologies (Figure 14, [23]). The main factors that impose AM technology on the market, especially for oil industry products, can be summarized as follows [23]:

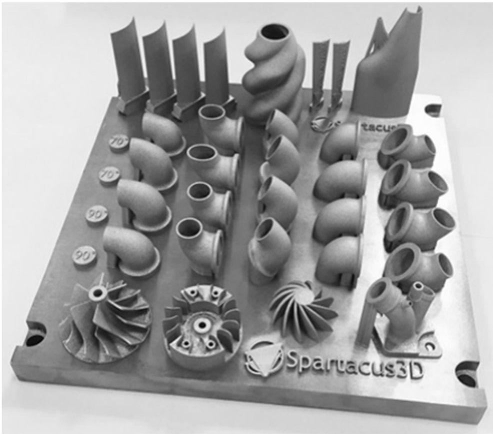


Figure 13. Parts made by AM technologies [22]

a) The relatively short duration of placing new projects on the market. An important advantage of 3D printing is the acceleration of product development. With AM's rapid prototyping capability, companies are able to develop and validate their projects faster, accelerating the design process enables companies to respond better to emerging market opportunities.

It is often possible to use 3D printing to shorten the development cycle of components in the oil and petrochemical industry, so reducing the time required for the production process. Rapid prototyping allows multiple design cycles to be performed and design concepts to be quickly tested.

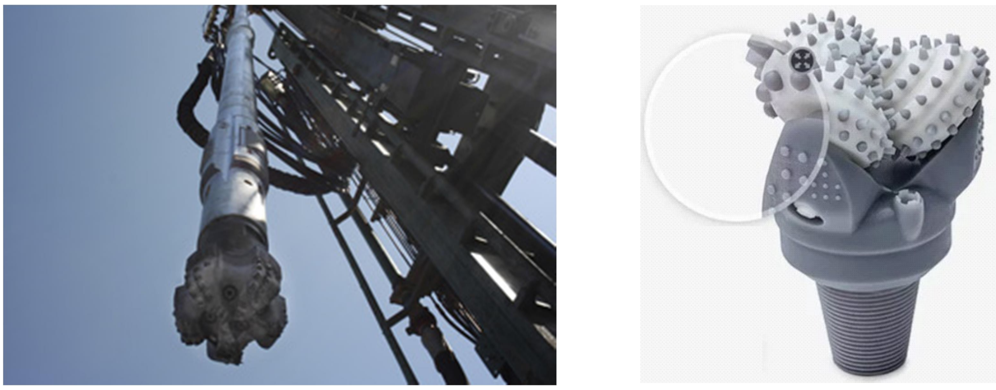


Figure 14. Drilling rig made by AM technologies [23]

b) The possibility to generate complex geometries. Parts manufactured using traditional technologies must be divided into component parts to allow for proper post-processing. For example, to allow the successful processing of internal surfaces, many parts must be made of two parts which are then welded. Instead, 3D printing allows monobloc manufacturing of parts. Additive manufacturing allows for innovative shapes and complex geometries that reduce the number of parts, so reducing assembly time performance is improved. Compared to traditional casting, additive manufacturing allows the simplified manufacture of pumps, turbine rotors, valves and other products, which can reduce costs and increase performance.

c) Manufacture of spare parts. Oil and gas operators face significant logistical challenges, due in part to the wide geographical distribution of operations on continents and oceans. The high cost of downtime exacerbates the critical storage situation. AM reduces stocks in the warehouse by printing on demand. In some cases, the quality of 3D printed spare parts exceeds the quality of the original ones.

CONCLUSIONS

Additive manufacturing (AM), also known as 3D printing, is a process of creating prototypes and functional components made by consolidating the material layer by layer. Applications of AM technologies have been observed in the medical, automotive, architectural, electronics and aeronautical industries. Some of the main benefits of MA include efficient use of the material, new design possibilities, improved product functionality and flexible production. Opportunities for additive manufacturing applications in the oil and gas industry are just being explored. The adoption of AM technologies required a rethinking of the design for the manufacture and assembly of oil and gas components, such as high-tech burners, nozzles and submersible components of mud pumps, drill bits, elbows, fittings, centrifugal pump rotors, reactors catalytic converters, heat exchangers, etc. The possibility of using on-site AM technologies for the production of spare parts, for the replacement of damaged components in oil and gas equipment and installations is very important, as this reduces production downtime and replacement costs. The future of AM in the oil and gas industries is extremely promising, however, before AM can realize its full potential in these industries, further research is needed in the development and processing of new materials, improving the surface finish of AM manufactured parts.

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