The Use of Additive Manufacturing in Maritime Industry

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Abstract — *Because of some important advantages, Additive Manufacturing (AM), also known as 3D printing, become more popular and begin to take more place in different sector like aerospace, automotive, healthcare ,etc. Especially, since the filament-based method can easily found and installed at home or at small workshops, AM has also become an area of interest for personal use. Advances in the use of metal additive manufacturing have opened up a lot of possibilities for production. In this paper, authors examine the use of Additive Manufacturing technology in a relatively new field: Maritime industry. Firstly, a piece of general information about AM is given and then the possible usage areas of AM, particularly in the maritime industry are mentioned. The advantages of using AM is evaluated in a wide range from prototype construction to supply chain of spare parts.*

Keywords — *Industry 4.0, Additive Manufacturing, 3D Printing, Maritime Industry.*

I. INTRODUCTION

The rise of new digital industrial technology, known as Industry 4.0, is a transformation that makes it possible to gather and analyze data across machines, enabling faster, more flexible, and more efficient processes to produce higher-quality goods at reduced costs. Advanced digital technology is already used in manufacturing, but with Industry 4.0, it will transform production. It will lead to greater efficiencies and change traditional production relationships among suppliers, producers, and customers; as well as between human and machine. Nine technology trends form the building blocks of Industry 4.0 (Fig. 1):
Autonomous Robots, Simulation, System Integration, Internet of Things, Cybersecurity, Cloud Computing, Big Data, Augmented & Virtual Reality, and Additive Manufacturing.

Additive Manufacturing (AM), is an appropriate name to describe the technologies that produce physical 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete, etc. using computer-based 3D design [1].

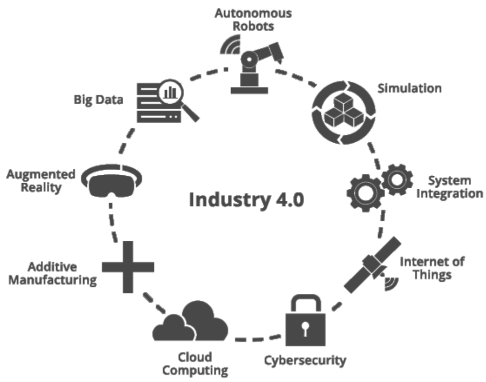

Fig. 1 Industry 4.0 Technologies

The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. AM has improved tremendously in the last decade and has progressed from primarily being used for prototyping to actual production. Advances in the use of metal additive manufacturing have opened up a lot of possibilities for production.

AM story is starting from the 1980's [2]. Despite being a new technology, the first 3D printer was produced in 1983. Due to the expiration of the patent period of the first writers, interest in these printers has increased in recent years [3]. The growth rate of AM was 24,1% in 2010 according to Wohler's report [4]. According to Jeff Immelt, CEO of General Electric, additive manufacturing is a new game changer in manufacturing. By 2020, General Electric (GE) Aviation planning to produce over 100.000 3D printed parts for their engines with $3.5B investment.

The process takes place basically as follows; the process begins with creating a 3D Computer Aided Design (CAD) model of the product with all dimensions and details. Then, this CAD file is split into very thin 2D layers by a computer program. Next, these very thin 2D layers send to 3D printer one by one. The layers build by machine as each layer on top of the previous one. This process may take ten minutes or ten weeks according to product detail [1].

One of the important features of AM is the surface quality of the final product. Regarding surface quality, Boschetto [5] worked on the development of a mathematical profile used to know the roughness of the surfaces. Krolczyk [6] studied on the analysis of the texture and roughness of the surfaces of the machined parts manufactured via Fused Deposition Modeling (FDM) method. The aim was to observe the surface totally of these parts and it was found that FDM surface had steep gradients, the smooth gradients existed on the surface. Thanks to the latest technologies, 3D printed products can be produced with the help of conventional methods and the final products with better surface quality can be obtained.

There are also numerous works in the literature about the mechanical behavior of 3D printed products. For instance, Vicente [2] investigated resistance of ABS Material used 3D printed parts according to their infill pattern and density. In his work, he used standard infill patterns like honeycomb, rectilinear, etc. He found that the dominant effect was changed due to density changes. According to his work, although the infill pattern changes the strength of less than 5%, the density changes the strength more than the infill pattern. Lu et al. [7] studied on a method to make the weight and cost more less than present works while keeping the strength of the parts as possible. They used a hollowing optimization algorithm based on cell structures which have honeycomb shape and created less-weight parts with the same strength.

A. Additive Manufacturing Methods

The different methods used for AM can be listed as follows according to the development date: Stereolithography (SLA)(1986-1988), Solid Ground Curing (SGC) (1986-1999), Laminated Object Manufacturing (LOM) (1985-1991), Fused Deposition Modelling (FDM) (1988-1991), and Selective Laser Sintering (SLS) (1987-1992) [8].

Stereolithography (SLA): This method is based on the laser system. Laser beam come across one of liquid photopolymer layer and stacking individually that layer on top of one another. The primary reasons for selecting SLA is the laser system allow the start and stop the built at any given layer [9]. Because the focus diameter of the laser is smaller than the nozzle diameter where the material is extruded through, SLA process can be selected if very tight tolerances are needed.

Solid Ground Curing (SGC): It is a similar method with SLA which uses ultra-violet radiation as the energy source. The difference is that in SGC method, a mask is used to create a layer on liquid. Ultra-Violet radiation cannot pass the mask, so only regions exposed to light will cure. When one layer is created, the liquid box gets deeper and other layer starts processing [10].

Laminated Object Manufacturing (LOM): This method is based on paper type material usage. Laser cuts the sheets of paper for each layer and moves through to Z-Axis after every layer is finished. The LOM Model's surface must be sanded after production for getting a smooth surface. LOM process has more advantages than other methods, like; very large parts can be produced with very low internal tensions and with high durability. Also, the materials of the LOM are easy to handle and dispose of because they are non-toxic and non-reactive [11].

Fused Deposition Modelling (FDM): FDM also starts with the CAD model. The CAD model is sliced into a multiple-layer data format and these slices are converted to some numerical codes [12]. The codes are used to define the movement of nozzle and platform. The Nozzle moves on the X-Y plane. When the first layer is completed, the platform moves down through Z plane. The Second layer is built on this first layer by the material which is coming from a nozzle. Another name of FDM is Fused Filament Fabrication (FFF). The material is mostly plastic which is stored in a filament spool as filaments. FDM method is the fastest method for large objects. Also, infill percentage is one of the most important parameters for the FDM method. That parameter gives the designer to be flexible for adjusting the weight, strength and etc.

Selective Laser Sintering (SLS): SLS is creating products from the powder of material. The way is, welding layers of powder material on top of each other (Fig. 2). Welding action produced by thermal energy and is supplied from a laser beam. After a layer welding is finished by laser, powder deposition system spread thin layers of powders (0.1-0.3mm thickness) before the laser action for another layer [13]. Unlike SLA, this method has some flexibility to use the material for creating 3D products as like plastics such as nylon and polystyrene and metals like steel, titanium.

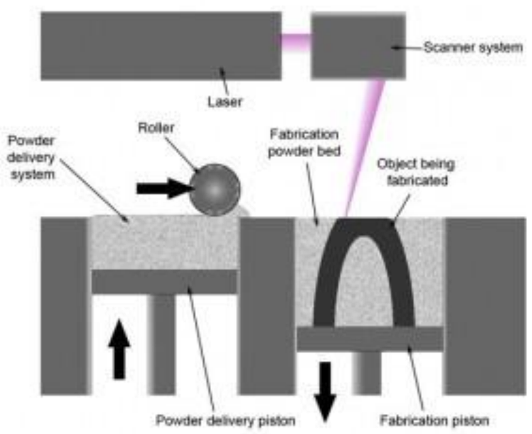

Fig. 2 Selective Laser Sintering (Credit: Laser Prototypes Europe Ltd.)

Wire Arc Additive Manufacturing (WAAM): This is an application whereby parts are produced using the combination of an electric arc as a heat source and wire as feedstock. It has a certain similarity to FDM technology, by welding wires to build near net shape parts in layers. The raw part is built in 3D on a 5axis build platform. Maximum part size is 1 m^3. The raw part undergoes CNC milling to get its final condition. The benefit of this method is high material efficiency which enables 60% decrease of manufacturing costs when compared to conventional subtractive CNC technology and builds rates that outrival any powder-bed-based AM technology. Areas of application are aviation, automotive, and machinery, but WAAM is also recommendable to manufacture outstanding design products.

II. ADDITIVE MANUFACTURING IN MARITIME INDUSTRY

In recent years, Additive Manufacturing has been started to use in several industries, especially in aerospace, automotive, and healthcare. As a result of both the development of different methods and the improvement of the properties of the materials used, the use of AM has started in many different sectors. There are also some examples of use in the maritime industry, although it is not yet very much, and it is predicted that the usage rate will increase gradually in the coming years.

The priority areas where AM technology is being used in the maritime industry and possible applications can be listed as follows:

- Prototype manufacturing
- Manufacturing of the main structural elements of yachts
- Spare parts manufacturing

A. *Prototype manufacturing*

Designers and customers generally want to see the final design in a more realistic way than a 3D CAD model and one of the best ways to do that is with prototypes. However, it is hard and time-consuming to produce complex prototypes by conventional manufacturing. After 3D printing technology, lots of companies start to produce 3D-printed prototypes, not only for visual shows but also for use in a different type of tests like a model test, temperature test, and strength test. It can be said, Prototype manufacturing is growing up faster than other parts of additive manufacturing. As a result, using AM, it becomes easier to produce prototypes that are cheaper and manufactured in a shorter time. Additionally, as the human effect during production is eliminated, the final product obtained is equivalent to the 3D CAD model.

One of the most successful examples is the resulting product of the collaboration between the Oak Ridge National Laboratory and the U.S. Navy: a submarine hull prototype in only 4 weeks. The laboratory has used “Large-scale Polymer Deposition” to produce the 6 carbon fiber composite material sections. With conventional manufacturing method, this submarine is cost like 600.000 $ and building period will be like 3 to 5 months.

B. *Manufacturing of the main structural elements of yachts*

There are several works about building the main structure of the yacht using 3D printing technology. One of them is based in Italy. Livrea Yacht (Fig. 4) is an ambitious project of two Italian boat builders, Francesco Belvisi and Daniele Cevola, the winner of Italy’s National Innovation Award 2017. Two entrepreneurs are building a mini-transatlantic sailing yacht with using 3D printing technology since 2014.

In parallel to the yacht project, they have driven the development of a dedicated direct extrusion 3D printing technology with their company OCORE, which is providing the required quality of parts. Besides, an improving the printing hardware - robot, extruder, and nozzle – they have patented a new material deposition strategy using an algorithm inspired by fractals. LUVOCOM 3F is the material which is using in this printing work, based on thermoplastic polymers, such as high-performance polyamides and PEEK. These polymers are reinforced with carbon fibers to achieve required mechanical properties. Because of this material, 3D printed structure part improve layer strength. This leads to more durable, much stronger and at the same time lighter parts.

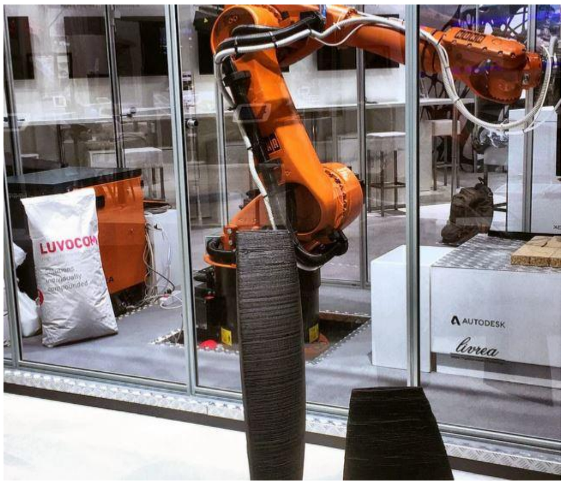

Fig. 3 Livrea Yacht Printing Hardware (Credit: Ocore)

Designers reported that the boat will be highly competitive thanks to the light and strong 3D printed parts. The use of 3D printing reduces the build time for the boat dramatically and makes it also cheaper.

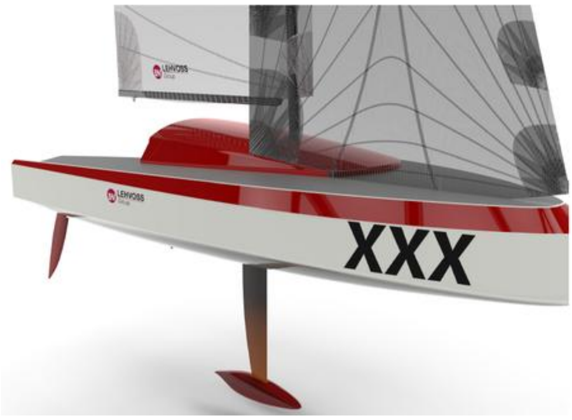

Fig. 4 3D Model of Livrea Yacht (Credit: Lehvoss)

C. Spare Part Manufacturing

Nowadays, parts that can be produced with 3d printing have dimensional limits due to the strength of the material used. For this reason, the use of AM has become more common in the production of small parts instead of the whole boat. Thanks to new material technology 3D printers can produce end-use parts, such as a propeller.

RAMLAB is a 3D printing laboratory which is focusing on spare parts in Rotterdam. One of the great maritime applications of 3D printing was developed by RAMLAB with a partnership of Damen Shipyards Group, Promarin, Autodesk and Bureau Veritas; companies who teamed up to print a premium boat propeller. The propeller, which weighs approximately 180 kg and measures 1300 mm in diameter, will be printed from a bronze alloy using the WAAM (Wire Arc Additive Manufacturing) process. After a rigorous testing process, verified by Bureau Veritas, the WAAMpeller (Fig. 5) become the world's first class approved 3D Printed ship's propeller at 30 November 2017.

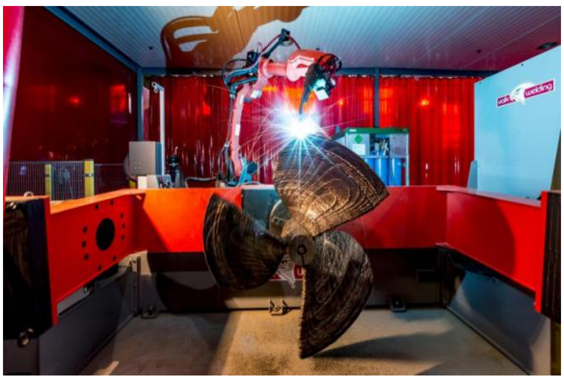

Fig. 5 WAAMpeller in Production (Credit: RAMLAB)

At the sea condition after long periods of exposure to wind, weather and regular use; lots of the parts need to replace in a ship. For a cargo ship, a cruise ship or a small yacht they all have this problem in common. For the big-sized ships, a missing part can create expensive problems because of the route plan or rent of the port for extra anchoring days. As a result of similar problems, some companies also planning to add 3D printers on board. Thus every vessel can produce their unique part by themselves during their navigation. For instance, French company Lab-R.E.V. has decided to put 3D printers onboard to test to see how it can be incorporated in seafaring vessels, and also U.S. Navy decided to use 3D printers on USS Harry S. Truman aircraft carrier.

Latest researches show the applicability and advantages of using AM and the effect on conventional spare part supply chain (Figure 5). Holmström [14] show the following advantages of AM:

- No need for tooling
- Small production batches can be created economically
- Products can be optimized for function
- Supply chains with shorter lead times
- Supply chains with lower inventories

Also, using AM in industry minimize material waste by as much %90 [15].

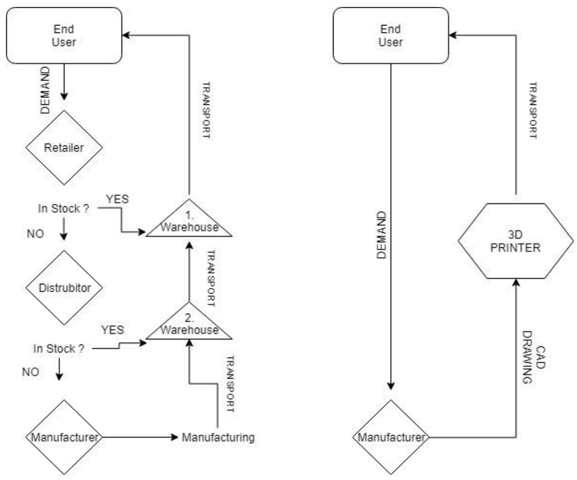

Fig. 2 Supply Chain Changes with 3D Printing Technology

III. CONCLUSIONS

In this paper, a piece of general information about AM was given and then the possible usage areas of AM, particularly in the maritime industry were mentioned. The advantages of using Additive Manufacturing in the maritime industry were discussed from prototype construction to supply chain of spare parts.

Early use of AM in the form of Rapid Prototyping focused on preproduction visualization models. More recently, AM is being used to fabricate end-use products, especially in aviation, aerospace, automotive and healthcare industries. However, it is clear that the rate of use in every field will increase day by day. AM is just beginning to be used in the maritime industry. One of the most important problems in ships is the need of spare parts during navigation. It will be a fast and cheap solution to spare part supply problems during long navigation periods by placing 3d printers onboard, so required parts can be easily produced by means of 3d printers using convenient CAD model and raw material.

Being able to produce spare parts by AM when necessary will also eliminate problems such as the continuous production and storage of these parts. This will be also a cost-reducing factor.

Today, AM can be also used to construct the whole vessel, especially small-sized for personal use. However, in the near future, it could be possible to construct bigger hulls as a result of the developments of 3D printers and materials.

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