# USE OF 3D PRINTING TECHNOLOGY IN MARITIME INDUSTRY

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**Abstract**:Maritime industry, despite being conservative to changes, it has scope for the usage of a new methodology in construction of various devices and components. it is better known as 3D printing or the Additive Manufacturing technology (AM). This technology has flourished in various other sectors. The new technology comes with benefits for the companies that choose to adopt. As AM is starting to consolidate in the industry, it offers a variety of changes in the shipping industry. Additive Manufacturing (AM) or 3D printing has potential of being more cost effective, cleaner and mass manufacturing of parts.

The AM technology deals with addition of material unlike the existing technology of subtractive manufacturing. The process uses voxels as basic block building elements placed in layers to develop the desired component. The AM technology has been emerging out successfully in the global landscape and has huge growth opportunities in the coming years in maritime sector. Due to low market awareness, cost constraint and lower domestic production this technology has been facing hurdles in shipping industry. This process has been successful in developing numerous prototypes in marine industry. Considering the characteristics of maritime sector and the advantages of the AM process, the AM process is seemed to have a large scope of development in the upcoming years.

## 1. Introduction

Additive Manufacturing (AM) which is also known as 3D printing has been already implemented in various sectors like (automobile and consumer products, medical, industrial, aerospace, etc.). It is based on the principle of the construction in layers by converting the data from the software in 3D form into physical objects .By using this method we can produce functionally incorporated components including spare parts in single production step but in small batches. We obtain a lot of benefits from this technology one of which is that we obtain flexible production with no extra expenditures of manufacturing. We achieve this by transforming the designs of 3D data made in the software into physical objects, without the need of any additional tools. Moreover, by using the principle of the construction in layers we can produce functionally incorporated components in single step production, so this obviates the assembly of components. When we compare it with conventional production it has numerous advantages like better design specifications , low manufacturing time, high energy efficiency, emission free etc.

Maritime assets are capital-intensive and their out of service time has economic consequences. They usually operate away from the base at remote locations and are on continuous move. Some

other sectors which share similar characteristics are aerospace, defense units and automobile. We will explore how lessons learnt from various sectors can be applied to shipping industry.

In this presentation, we firstly discuss about the available technology which can be used and is currently being used and understand the concept of additive manufacturing, materials which can be layered into components. Then we step into the understanding the characteristics of maritime sector and how it has been adapting to the changes in technology. Further we see how 3D printing can be used in the maritime sector. Next, we are going to discuss how ports can be used as manufacturing hubs. We move on to explain the supply chain used in the production process using this technology and we put together the advantages and disadvantages of using this technology in the shipping industry.

Followed by applications which are being developed or those which are already developed using this technology in the maritime field. Then we look at some mathematical calculations involving the manufacturing cost. Lastly we discuss about the process of Additive Manufacturing.

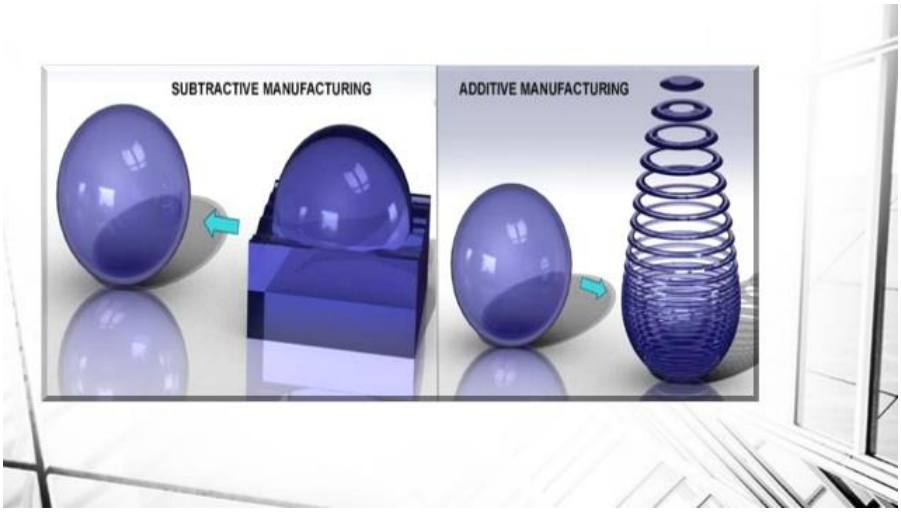


Fig. 1 Difference between additive and subtractive manufacturing process

## 2. Available Technology

Additive Manufacturing is the official industry standard term (ASTM F2792). It is also known as additive fabrication, additive processing, freeform fabrication and additive layer manufacturing. Voxel is the basic block in the AM technology, Addition of numerous voxels in a specific design in layers we obtain the desired structure. In some processes the material is squirted, squeezed or spread and in others fused, bind or glued. The power source is thermal, high powered laser beam, electron beam, Ultraviolet laser or Photo curing. The raw materials for the process are polymers, metals, ceramics, composites and biological materials. The starting materials could be liquid filaments/paste, powder or solid sheet. Currently the most common metallic materials are steels, pure titanium, titanium alloys, aluminum casting alloys, nickel based super alloys, cobalt-chromium alloys, gold and silver.

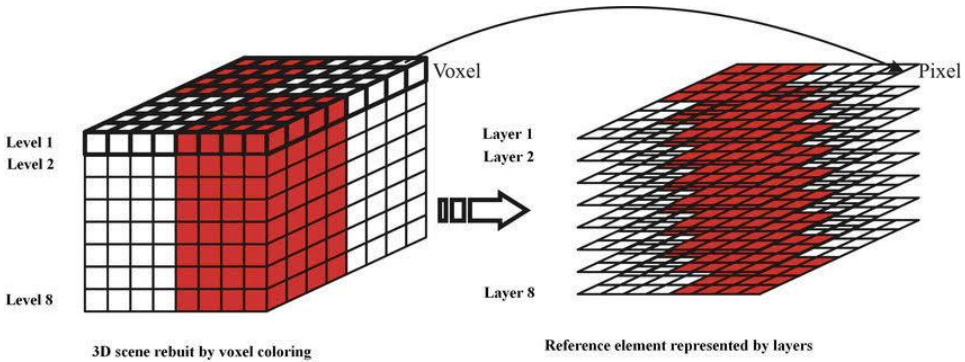

Fig.2 Construction of element using voxels arranged in layers

AM houses several processes and are classified into seven types:

1. Binder Jetting
   AM process where in a liquid bonding agent is deposited to join powered materials together.
2. Direct energy deposition
   AM process where thermal energy fuses or melts the materials together as they are added.
3. Material Extrusion

   AM process that allows for depositing material via a nozzle.

4. Material jetting

   AM process where droplets of materials are deposited

5. Powder bed fusion

   AM process where thermal energy fuses or melts materials from a powder bed.

6. Sheet welding

   AM process where sheets of materials are bonded together.

7. VAT photo-polymerization

   AM process where liquid photo polymer in VAT is cured by light.

## 3. Characteristics Of The Maritime Sector

The Maritime Industry has been following its traditional and orthodox techniques for a long time. It has offered a significant amount of resistance to new technologies but has accepted a few technologies taking into consideration its advantages environmentally and economically. Before the introducing the AM or 3D technology in this sector it becomes necessary to understand its characteristic nature, so the following points are in view with the nature of the maritime sector.

Maritime assets are capital intensive and downtime has financial consequences. The working environment of vessels is governed by the dynamics of the ocean which in turn provides an environment in continuous motion. The ships are subjected to constant motion and carry out its operation in remote areas away from the ports. So the ships are isolated from repair facilities and spare parts storage. The working environment here is highly corrosive with turbulence and vibrations caused by the machineries, non-calm weather and rough seas.

The maintenance networks are involving many components such as the owner of assets, system integrator, original equipment manufacturers (OEM), service providers and their logistic service

providers. The outgoing vessels have workshops onboard staffed with technicians, who have to solve the problems of the mechanical equipment that appear while working in harsh conditions.

## 4. Additive Manufacturing In Maritime Sector

Maritime will not be left out of technological developments on the information technology. However there are only a few published case studies of applications in real situations, there are initiatives in place. Apart from general prototyping applications, there are about parts maker tests and application in ships both in defense and commercial sector.

- The largest container carrier company in the world, Maersk line has found out a way to produce spare parts onboard by the means of 3D vessels. In 2015 the company had revealed that it switch to the use of fabrication of spare parts by installing 3D printers on the container vessels. It used ABS thermoplastic materials to build the components. However the company believes in the use of the powder based metal laser sintering printers in order to enhance variety of processed components. The company plans to remove the hauling of spare parts of the container vessels. The 3D printing process would not only benefit the container vessels but also revolutionize the tankers.
- Damen Shipyards Group, RAMLAB, Promarin, Autodesk and Bureau Veritas teamed up to print a premium boat propeller, WAAMpeller which weighs 180 kg approximately and has a diameter of 1300 mm. This propeller was constructed using Wire Arc Additive Manufacturing (WAAM) process which used a bronze alloy

Fig. 3 Picture of a boat propeller better known as WAAMpeller.

- The Italian startup Livrea and the American software company Autodesk have come together to produce the first 3D printed yacht. The traditional Sicilian method gave way to the AM or 3D techniques for printing of entire yachts.

Fig.4 3D printed Yacht by Livrea and Autodesk

- To maximize the output from the tidal currents, scientists have made efforts to harness this energy by turning to 3D printing. The researchers printed two turbines with diameter 150mm*100mm which possessed mechanical functionality, lower costs and great strength.

## 5. Ports As Additive Manufacturing Hubs

Merchants and Defense vessels are dependent on the ports for maintenance, repair and replacement of the machineries onboard. Ports are expected to be potential additive manufacturing hubs. The ports are static in nature and are not subjected to any movement so ports can flourish as AM hubs another thing which can enhance ports as AM hubs is large spaces for printing of parts and storing the printed parts.

## 6. Spare Parts Supply Chain In Maritime Industry

In the maritime industry we constantly use machineries and equipment for specific operations. The vessels work in extreme working conditions making safety and reliability requirements critical.

The IMO and various classification societies have laid down restrictions and regulations on the type and quality of the components manufactured in order to prevent untimely and unexpected breakdown of components. Usually failure of machineries can occur anytime due numerous reasons in case of severe damage machineries needed to be replaced so availability of spare parts becomes a question. Carrying spare item of each device is also practically not feasible. Hence supply chain of spare parts plays an important role.

Consider a merchant or a defense vessel travelling at a certain speed at a given point of time and is found to be at position A, so in case of failure of any machinery onboard it needs to be replaced or repaired immediately. Here the supply chain of 3D printed spare parts comes into picture, As soon as the machinery breaks down a signal is sent to the technical department on shore who receive the information regarding the issue and refers it to the procurement department. The procurement department as the name suggests collects the parts required for the machinery considering all the dimensions of machineries and prints it completing its duty by sending it to the supplier. The Supplier plays a crucial role which involves transporting the additive manufactured parts to the vessel from the port. When the vessel reaches position B it receives the printed parts from the

supplier and thus the machinery is brought back to working condition, this is how the supply chain in the maritime industry is structured.

To bring about the effectiveness and make the AM technique sustainable in the maritime sector each component of the supply chain has to perform its function appropriately. Even if a single component fails to accomplish its duty, major failure of the supply chain can take place.

## 7. Advantages And Disadvantages Of Am

Though 3D printing technology or AM has flourished in other sectors such as aerospace, aeronautical, architecture, automobile, commercials, etc., there's no significant contribution in the maritime sector of the aforementioned manufacturing process. However the detailed study of the same proves to be advantageous in mere future. As this process is additive in nature, it does not involve wastage of material by removal of excess unwanted chunk of material as in the subtractive manufacturing process. The basic benefit from this technology is less use of material, lower production cost which is directly proportional to the amount of material used. The time taken to prepare a component through 3D manufacturing is way too less in comparison with the existing traditional manufacturing process.

The world's largest 3D printed boat was built in mere 72 hours. The durability, strength and robustness are commendable when the 3D printed structures are subjected to stress and forces of higher order when they are expected to meet with minimal damage. The maintenance and the labor required is drastically less thus reducing the initial cost.

However as the process seems to be beneficial in various aspects of production and maintenance there is a threat of prevailing disadvantage as the printing process is dependent on the gravitational forces of attraction, the construction seems to be problematic on the vessel due to the stability of the ship. When the ship makes way through the water it undergoes various motions wherein the center of gravity changes with time thus making the ship motion dynamic in nature. So the process faces major disadvantages as the ship is not static.

## 8. Applications Of Am In Maritime Sector

Though additive manufacturing is new to the maritime sector, it has made progress to produce working models along with few basic prototypes.

1. PRINTING OF SUBMARINES
   Recently a 3D printed submarine prototype was brought into existence for the U.S. Navy.
2. MANUFACTURING OF BOAT PROPELLERS
   Various groups have come together to prepare a 3D printed propeller named WAAMpeller.
3. PRINTING OF SPARE PARTS FOR NAUTICAL RACING
   Using Direct Laser Metal Sintering (DMLS) innovative design of racing boats came at much lower costs.
4. MAPPING OF SEA FLOORS
   Recently a Canadian company International Submarine Engineering (ISE) with the help of EBAM and VB processes is undertaking mapping of arctic seafloor.
5. PRINTING OF SPAREPARTS
   Durable, Robust, Strong, Cost effective, light weight and time effective spare parts are manufactured.

6. PRODUTION OF YATCHES
   LIVREA yatch was printed by American software company Autodesk.
7. PRODUTION OF DRONES
   The U.S CICADA Navy drones have emerged out as a new advantage of 3D printing.
8. PRINTING OF CHAIN MAIL IN SHIP
   This medieval instrument of protection was put back to use in a new way by the masterminds of NASA.
9. PRODUCTION OF TURBINES
   Another advantage of 3D printing which helps to harnessing tidal current energy by the production of turbines.

## 9. Mathematical Calculations

- Material cost
  Material cost = p * pi * (D/2)^2 * L * price

  Where p = density of material
  D = diameter of filament
  L= Length of filament used
  Price is the cost of material per unit weight.
- LABOUR COST
  Labor cost = T * R
  T= time needed to finish the job.
  R is the cost per 1 hour of 3D printing.
- Final Price
  Final Price = (material cost + labor cost) * (markup)
  Markup is ratio of profit to cost.

## 10. Additive Manufacturing Process

The process of additive manufacturing starts with developing of a 3D model by using various designing software's like Tinker CAD, Blender, BRL-CAD, etc. As per the plan of the parts to be produced, 3D models of appropriate dimensions and structural features are worked on in these software's. This model in the form of software is sent to the 3D printing machine in the format of an instruction file and then direct transformation of 3D data stored is simply supported by supply of raw materials to the machine.

## 11. Case Study

The Oak Ridge National Laboratory in collaboration with the U.S. Navy which created a submarine hull prototype using the Big Area Additive Manufacturing (BAAM) in mere 4 weeks. The submarine printed was 30 feet long, comprising of 6 carbon fiber composite material. The average cost of manufacturing of a submarine on an average is $700000 and expected time to build a submarine hull takes up to 3-5 months. By the use of 3D technology the construction is expected to reduce by 90%. After successful completion of the concept of hull, the next step will be taken to create a watertight version that will be tested in the wave version that will be tested in the wave pool at Carderock. This will help to enact the actual conditions a submarine has to face in the oceans.

Fig Picture of 3D printed submarine hull prototype by the U.S. Navy

## 12. Conclusion

After a detailed study of the AM or 3D printing process, all the aspects such as working procedure, raw materials, advantages , disadvantages, applications and supply chains this is regarded as a boost to the maritime sector in various dimensions such as reducing of production time , initial production cost , maintenance, weight and manpower.

However the process is successful in manufacturing of prototypes and a few full scale designed structures.3D printing is seen as a potential change in production of various other vessels, turbines, propellers and other structures against the conventional construction methods.

The production process requires fundamental knowledge of working with design software and the rest manufacturing process being a mere cosplay.

Installation of 3D printing machines on ship is a task of concern but ports are seen as potential additive manufacturing hubs. This brings in the effectiveness of the supply chain to be established between the port and the vessels.

The AM manufacturing technology uses various principles for production such as joining of powdered materials using a liquid bonding agent, fusing of material using thermal energy, curing of liquid photopolymer in vat.

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