Wire Welding in additive 3D metal printing manufacturing

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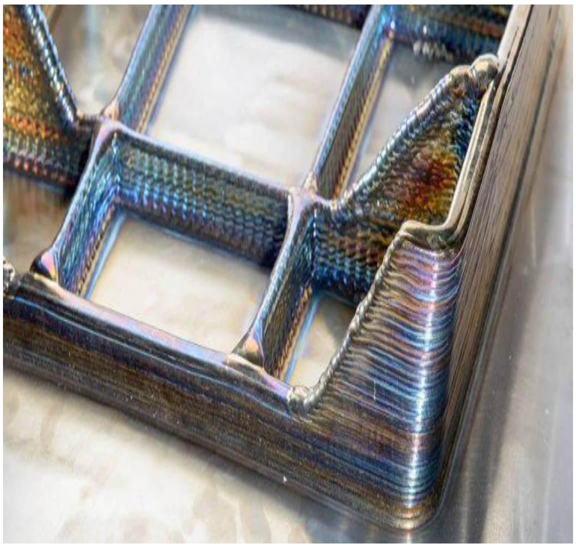
According to reports, the global 3D printing industry is expected to exceed $21B in worldwide revenue in 2020. Much of this growth comes from an explosion in using 3D printing manufacturing, something previously thought impossible when the process caught on during the 1980. The maritime industry spends billions of dollars every year on spare parts. 3D printed spare parts utilizing on-demand additive manufacturing – eliminating the need for physical inventory storage, often complex distribution, and typically high logistics costs will be very much part of the future. Already, it is very likely that the spare part you receive onboard your vessel will be an Additive Manufactured (AM) part.

Additive manufacturing (AM) is where a part is made by adding material, whereas the subtractive manufacturing (SM) process is where a part is made by removing material. In 3D manufacturing, a 3D printer makes a three-dimensional object from a CAD (computer-aided design) file. There are a variety of materials and 3D printing technologies available, making it easier than ever to create parts for all sorts of industries including parts used onboard ships.



Up to recently additive materials used have mainly been plastic and polymer (TPU, nylon and addition of carbon fibres), plus ceramic. Request for metal component spare parts are however in demand.

Powder-based materials were used before wire-based materials to AM fabricate metal components. Powder-based materials are still in use but they are more suitable for the fabrication of small components because of better geometrical and dimensional accuracy. However, the deposition rate and the fabricated build volume from powder bed based fusion process is relatively low. Thus, wire-based additive materials have been introduced to overcome the limitations of powder-based additive materials in large-scale metal component manufacturing.

Wire-based additive manufacturing (WBAM), Also known as Shaped Metal Deposition (SMD) has therefore been introduced due to its high potential for use in metal 3D printing. WBAM has advantages in terms of material usage efficiency, as the wire additive material is fully deposited into the metallic parts or components. Besides, WBAM has no limitations in terms of build volume.

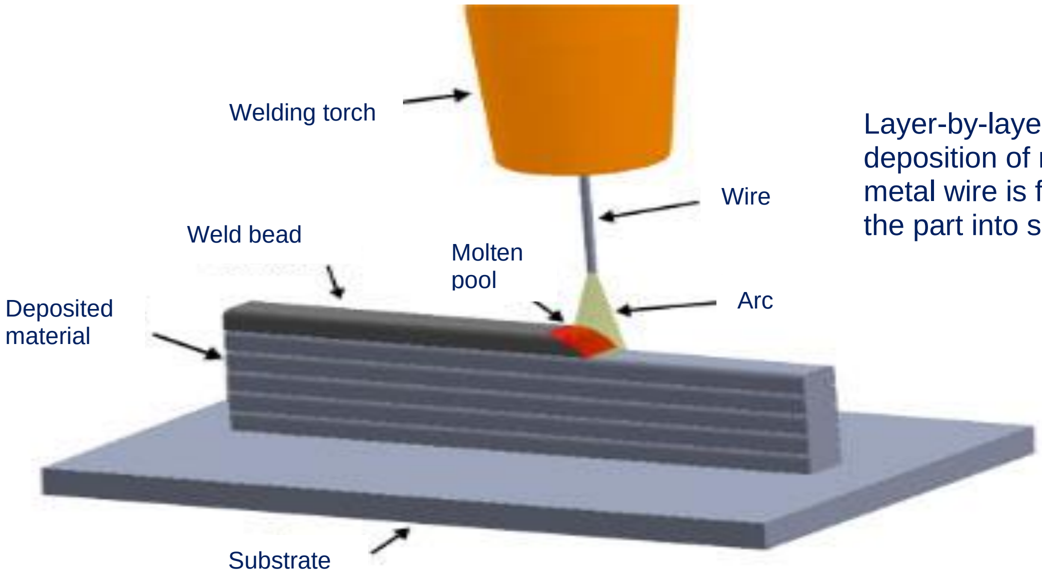
There are three different groups in WBAM:

Laser-based,

Electron beam-based

Arc welding-based > Wire arc additive manufacturing (WAAM)

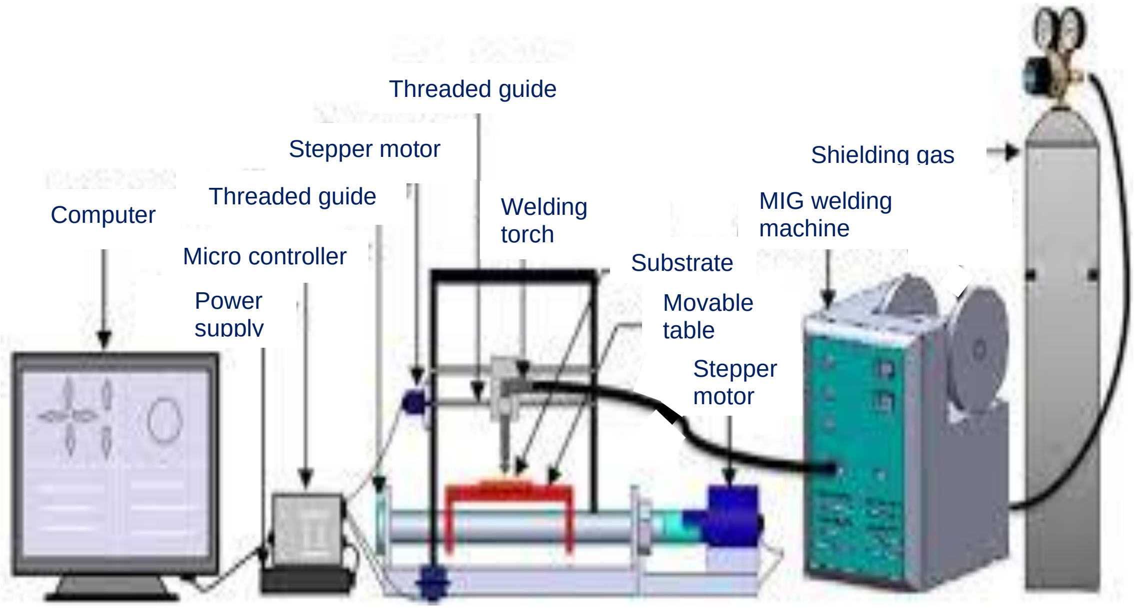
Generally, these groups have the same process but differ in their power sources and deposition rates. Laser-based and electron beam-based technologies are typically the same, as both of these power sources can produce 2–10 g/min deposition. The arc welding-based power sources have larger deposition among the technologies, as they can reach 50– 130 g/min. The deposition rate depends on the energy efficiency. Among the three power sources, laser-based has the lowest energy efficiency, approximately 30% to 50%, whereas the energy efficiency of the electron beam-based is slightly higher than that of the laser based. Arc welding-based has the highest energy efficiency, around 90%.



Layer-by-layer deposition of molten metal wire is forming the part into shape.

In wire arc additive manufacturing (WAAM) there are three heat sources commonly in use:
Metal Inert Gas welding (MIG)
Tungsten Inert Gas welding (TIG)
Plasma Arc Welding (PAW).

Letting a 3D printer using welding wire as a source material is combining a technically mature and highly reliable MIG arc welding method with CAD data. In this way fully dense metal parts by layering beads of fused metal is created. The parts can be finished using conventional machining to achieve a desired surface, holes, and tolerances.



There are four welding modes in MIG: the globular mode, short-circuiting mode, spray mode, and pulsed-spray mode. Reciprocating* wire feed (RWF) has later been introduced as modified MIG. RWF has better performance than MIG owing to its capability to produce a high deposition rate with lower heat input. TIG and PAW have the same welding process that produces the electric arc through a non-consumable tungsten electrode. Unlike MIG, TIG and PAW need an external wire feed machine to supply the additive materials.

Reciprocating wire feed gas metal arc welding (RWF-MIG) is a low heat input, precisely controlled variation of the MIG process. With the RWF-MIG process the wire is reciprocated in and out of the weld pool. The wire motion is synchronized with the current waveform to produce a weld that is characterized as having minimal if any spatter, and very controlled heat input, bead placement, and base metal dilution. Manufacturers of RWF-MIG equipment include Jetline Engineering (Controlled Short Circuit (CSC)), Fronius (Cold Metal Transfer (CMT)), SKS Systems (micro-Mig), and Panasonic (Active Wire Process (AWP)).

Wire Arc Additive Manufacturing (WAAM) can significantly reduce costs and improve production efficiency in industrial fields. Aluminum alloys, titanium alloys, stainless steel, nickel alloys, and mild steel are the additive materials that are often used in WAAM. Never the less, WAAM is inferior to other AM technologies in terms of accuracy and surface roughness. On to this comes that WAAM gives high thermal input and can generate residual stress and distortion, but counterstrategies have been put to use. New improved welding power sources like RWF-MIG give much more accuracy to the weld deposit than previously. Firstly, a stable welding process and effective heat dissipation. The welding process is sufficiently low energy so that when a new layer is applied, the existing layers do not melt again. In other words, the process is as "cold" as possible without reducing quality.

*Reciprocating in engineering: Moving back and forward.

Furthermore, the weld layers will be continuous, spatter-free, and consistent. If any flaws were to occur, these would be replicated in each subsequent layer. The welding machines process control must meet these requirements. It must produce a stable arc and a controlled short circuit with long short circuit times. This means that the heat input is lower and the material transfer is practically spatter-free, which helps to prevent flaws. Another strategy is through a roller application method, in which bulk deformation can reduce residual stress and distortion. The roller slides through the layer to minimize porosity and refine the grain size. This method produces better-quality printed parts than does normal WAAM.

Large parts, anything larger than 300mm (1 ft.) by 300mm (1 ft.), rather than taking weeks to print the part using a powder bed system, it makes sense to look for a higher-deposition-rate process.

Wire Arc Additive Manufacturing (WAAM) is a demanding manufacturing process towards the type of welding machine being used:

The machines duty cycle must have sufficient margin to upkeep the power demand for welding the object.

The machine must have a special program for welding in 3D. The CAD interface is in the robot/manipulator.

The machines digital control technology must instantly assure stability and optimal arc balance, from arc ignition to completing the welding sequins. The welding machines digital management must permit the welding characteristic to regulate quickly and accurately. The welding parameters must be dynamically controlled and changed in real time. All this is important in order to give fast arc control in order to optimize drop detachment something that provides:
Stable welding arc, with almost no spatter or micro-projections.
Very reactive arc to the torch movement.
Reduced energy transmitted to the welded part (heat input).
Very linear transfer with optimal edge wetting at a very high speed of execution.

Also, the machines Wire Feeder with its drive roller system must ensure a smooth wire feed operation, particularly with special wires (Aluminium, Stainless Steel and CuSi).

Welding wires for wire arc additive manufacturing

Steel	Nickel based	Non-ferrous
1.2343 (tool steel) 1.2367 (tool steel) 1.4316 (corrosion resistant steel) 1.4370 (corrosion resistant steel) 1.4332 (corrosion resistant steel) 1.4430 (corrosion resistant steel) 1.4462 (high-alloyed CrNi duplex) 1.4551 (corrosion resistant steel) 1.5125 (mild steel) 1.5130 (mild steel) 1.3990 (invar) 1.4718 (for hard surfacing)	2.4831 (high-alloyed CrNi) 2.4856 (Alloy625) 2.4668 (Alloy718)	2.0921 (copper basis) 3.0805 (AL99,5Ti) 3.2245 (4043 Si5) 3.2315 (6082 MgSi1) 3.2371 (4018 Si7) 3.2585 (4047 Si12) 3.3206 (6063) 3.7165 (Ti6Al4V/ Grade 5) 3.3536 (5754 Mg3) 3.3548 (5183 Mg4,5Mn) 3.3556 (5356 Mg5) 3.3546 (5087 Mg4,5MnZr)

Other common types of 3D printer technologies are:

- **FFF Fused Filament Fabrication** (Also known as FDM FUSED DEPOSITION MODELING) This is the most common and affordable type of printing — most machines utilize this technology. They work by a process where a spool of filament of solid thermoplastic material (PC, PLA, ABS, PET) is loaded into the 3D printer. It is then pushed by a motor through a heated nozzle, where it melts. The printer's extrusion head then moves along specific coordinates, depositing the 3D printing material on a build platform where the printer filament cools and solidifies, forming a solid object. **Polycarbonate (PC)** is the undisputed king of materials for desktop 3D printing. In comparison to nylon at 7,000 psi, polycarbonate's tensile strength of 9,800 psi makes it the ideal choice for high-strength, functional components.

- **CFF Continuous Filament Fabrication.** CFF is an expanded Fused Filament Fabrication (FFF) process that works in addition to a Fused Filament Fabrication (FFF) printer to lay continuous fibre in a part. In this process, a printer utilizes a second nozzle to lay continuous strands of composite fibres inside a convention Fused Filament Fabrication (FFF) thermoplastic parts. Parts built with the Continuous Filament Fabrication/ Fused Filament Fabrication (CFF/FFF) process are strong and stiff due to their reinforcing fibres.

- **ADAM Atomic Diffusion Additive Manufacturing.** ADAM or bound powder deposition, is a process virtually identical to Fused Filament Fabrication (FFF) used to print metal. Atomic Diffusion Additive Manufacturing (ADAM) uses a filament comprised of metal powder and plastic binder — after printing, the binder is dissolved away and the metal powder is sintered into a full metal part.

- **SLS/SLM Selective Laser Sintering/Melting.** SLS yields incredibly precise plastic parts. In this process, a printer lays down an even layer of powder and then precisely sinters a layer, repeating the deposition and sintering process until the part is complete.

- **SLS/DMLS Selective Laser Melting / Direct Metal Laser Sintering.** SLS and DMLS utilize the same process as Selective Laser Melting **(**SLS), but use metal powders. Due to metal's higher melting point and the added risks of metal powder, these machines require higher power lasers and better enclosures.

- **SLA Stereolithography.** SLA printers can quickly and affordably produce precise parts. They utilize a laser to selectively cure a layer of resin, which is then pulled up and reset for the next layer. Typically, these parts are "pulled" upward out of the resin as they're built.

- **DLP Direct Light Processing.** DLP is a 3D printing technology and is almost the same type of machine as Stereolithography (SLA). The main difference being Direct Light Processing (DLP) uses a digital light projector that flashes a single image of each layer all at one time - or does multiple flashes for larger parts. Light is projected onto the resin by light-emitting diode (LED) screens or an ultraviolet (UV) light source, such as a lamp. It is directed onto the build surface by a Digital Micromirror Device (DMD), which is an array of micro-mirrors that control where the light is projected and generate the light pattern on the build surface.

- **MJ MATRIAL JETTING.** MJ is a 3D printing technology that uses photopolymer resin (Standard, Castable, Transparent, High Temperature) and works in a way similar to the common inkjet printer. The difference is, instead of printing a single layer of ink, multiple layers are built upon one another, creating a solid object. MATERIAL JETTING (MJ) differs from other types of 3D printing technologies that deposit, sinter, or cure build material with point-wise deposition. Instead, the print head jets hundreds of droplets of photopolymer and cures/solidifies them using UV light. Once a layer is deposited and cured, the build platform lowers by one-layer thickness and the process is repeated until the 3D object is built.

THE FUTURE WILL BE:
SPARE PARTS REQUIRED?
PRINT ONE!