Aeroswift: a large-scale powder bed fusion AM system

Hardus Greyling of South Africa's Council for Scientific and Industrial Research (CSIR) and Marius Vermeulen from Aerosud Innovation and Training, talk about Aeroswift, an R&D project involving the development of one of the largest laser-based additive manufacturing (AM) machines in the world and its use to define and industrialise powder bed fusion (PBF) technology for the manufacture of high-value aerospace and other components.

Hardus Greyling of South Africa's National Laser Centre and Marius Vermeulen from Aerosud Innovation and Training.

Through an R&D collaboration between aerospace company, Aerosud Innovation Centre (IC), and the Pretoria-based CSIR, Aeroswift was established to advance laser additive manufacturing technology in South Africa. "The official programme started in 2011 with funding from our Department of Science and Technology (DST) and the R&D partners," begins Vermeulen.

"At the heart of the programme is to better beneficiate South Africa's titanium resources, along with supporting an emerging high-value component manufacturing industry, locally and abroad," he continues.

"We have been developing laser and additive manufacturing capabilities for many years at the CSIR," adds Greyling. "We are currently commercialising direct energy deposition/laser metal deposition (DED/LMD) technology for weld repair applications in industry, including work for our local power utility, ESKOM. This system is designed to be mobile, so that repairs can be undertaken onsite such as, for instance, repairing large power station components," he reveals.

Aerosud IC, on the other hand, is key partner in the development of AHRLAC, an advanced, high performance, reconnaissance, light aircraft designed as a versatile and rugged, multi-role manned platform. "To achieve lowest possible weight and extended component life, AHRLAC was designed with additive manufacturing in mind and, with the Aeroswift powder bed fusion system we have developed, we have already started manufacturing commercial parts for the AHRLAC: the throttle grips, the engine condition lever grip and some titanium ducting components," says Vermeulen.

Aeroswift, he continues, is an R&D laser additive manufacturing platform that also serves as a prototype. "Ultimately, we aim to design purpose-built LAM machines to suit target applications – and while we are currently focused on titanium, this is not a machine limitation," he notes.

The Aeroswift powder bed fusion LAM machine was designed for big powder volumes of up to 2 000×600×600 mm, predominantly for manufacturing aerospace components in titanium.

DED/LMD versus PBF

Direct energy deposition using a laser power source, explains Greyling, involves depositing layers of metal powder on a fusion path and immediately fusing the powder at the focal point of a laser beam. The DED laser output and powder deliver systems are carried by a robot or multi-axis manipulator around the build area and gas shielding is needed to prevent oxidation and porosity along the weld path. "In general, the process is also used with plasma and TIG welding systems as heat sources, with wire often replacing powder as the material consumable," he says.

In contrast, powder bed fusion technology involves scraping a thin (50 to 100 µm) layer of powder onto a flat surface before using the focused laser 'spot' to fuse the first image onto that layer. "This is done in a purpose-built chamber on the base of a table. The table is lowered between each layer so that another layer of powder can be spread and fused, until the part has been fully manufactured," Vermeulen explains.

When the part has been completed, therefore, there is a full 'bucket' of metal powder with a fused part inside of it. The unfused powder is then shaken off and collected for reuse; while the part

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is cut off its base supports and sent for finishing.

Powder bed fusion is, in fact, a relatively old technology used originally for prototyping in the thermoplastics industry. When used with a laser on high value metals such as titanium, stainless steels, aluminium, nickel- or cobalt/chromium-alloys, the technology offers significant advantages compared to machining and other manufacturing methods: for lightweighting, for example, complex lattice structures can be easily manufactured using any of the layering techniques of additive manufacturing.

Comparing PBF and DED technologies, Vermeulen says that powder bed technology currently offers higher accuracy, better build resolution, and smoother surfaces. "We can make complex parts to high accuracies with our Aeroswift machine," he says.

Compared to precision-machined parts, small amounts of distortion will affect overall part dimensions, but this can often be managed and/or compensated for at build design stage and a quick final machining stage is often required, especially in high-tolerance areas of the part, to ensure the accuracy and surface finish required.

The DED process generally results in thicker walls and lower layer resolution – of about 500 µm. It is ideal for simpler geometries but it is, typically, faster. "A key advantage, however, is that laser-based DED systems can be used to fuse additions onto existing components.

"If a complex feature needs to be attached to a basic cylindrical form, for example, then the cylinder can first be accurately machined and the complexity added using an DED/LMD system," says Greyling, adding that this is known as hybrid manufacturing.

Centre on the platform is the titanium throttle grip for the AHRLAC, made in two parts using Aeroswift's PBF system.

The Aeroswift PBF system

The Aeroswift machine was designed to use big powder volumes, up to 2 000×600×600 mm, typically for manufacturing large aerospace components or batches of smaller components in titanium. "Aerospace is a business involving low volume, high value and high integrity applications and additive manufacturing is ideal for supplying this industry's needs. The process is also being successfully used in the medical profession for implants such as titanium lower- and upper-jaw reconstruction," says Vermeulen.

The Aeroswift machine itself was designed, developed and constructed from the ground up, focusing on the mechanical and optical systems and includes some commercially available sub-components, either directly or following adaptations to suit the purpose.

"The size of this machine makes this project particularly exciting. The powder bed is bigger than any commercially available technology and, while we know that other manufacturers are currently launching big machines, to our knowledge, ours currently has the largest build volume in the world," says Vermeulen. "We are also using a very high power laser: a 5.0 kW IPG fibre laser, in order to increase the production rate and reduce the costs," he adds.

Commercial units are typically using 400 W lasers, while some specify laser powers of up to 1.0 kW laser. "It's not simply about size, though. Our intention with the first machine was always to build a machine to develop advanced manufacturing capabilities, first serving as a flexible R&D platform to enable us to understand and optimise the technology; and second, to begin to produce production parts so as to realise the benefits as soon as possible," Vermeulen suggests.

The build volume was designed for full adjustability, with a movable bed enabling any build length to be accommodated. Via the control system every parameter involved in the build process can also be finely tuned: the laser spot size and power; the mirror scan rates and mechanical manipulator speeds; the powder feed rates; the overlap between adjacent laser tracks; the layer thicknesses, patterns and strategies; and the laser processing and shielding gas compositions. "Our controller gives us the flexibility to control and optimise every individual parameter," notes Greyling.

Due to the high cooling rates involved, titanium parts made using additive manufacturing often have a quenched, fine-grained martensitic-type microstructure. This gives very good tensile properties but poor elongation and toughness properties. "Generally, if the component properties need to match those of a wrought billet, we need to do an annealing heat treatment to soften the structure and to allow grain growth," he says.

"All in all, the idea is to optimise the processing parameters to achieve best possible material properties at high production rates, which is exactly what the aerospace industry needs," Vermeulen adds.

A purpose-developed controller gives the flexibility to control and optimise every individual parameter – even the functional material densities and strengths in different places of a component.

Titanium, SA and aerospace

South Africa, notes Vermeulen, has the second largest reserves of titanium deposits in the world, but no titanium metal is being locally produced. The CSIR is, therefore, looking at making metal from local ores, but is trying to avoid using the traditional and energy intensive Kroll process by making powder from titanium tetrachloride.

"The powder being manufactured at the CSIR's pilot facility is not yet suitable for us, because we need a spheroidised titanium alloy. But once this next step has been implemented, we see a supply chain going from local ores to spheroidised powder and, through AM systems such as Aeroswift, into making titanium components," says Vermeulen.

"If you ask why titanium has become so important in aerospace, we need to look back to about twenty years ago, when most aircraft were made in aluminium – 95% Al and 5% other materials. These days the likes of the Boeing 787 and the Airbus 350 are using in excess of 50% carbon fibre – and if carbon and aluminium are put together, the battery effect results in galvanic corrosion," he explains.

Titanium is an ideal replacement for aluminium as it is chemically inert due to its passive oxide layer on the material surface. Up to 14% of the material used in these new aircraft is now titanium, with the aluminium content being proportionally down. In addition, of course, titanium has an excellent strength to weight ratio and offers superior performance at high temperatures.

On the down side, however, it is an expensive material and difficult to manufacture using traditional techniques. During casting, titanium is very reactive and sensitive to oxygen and mould materials. And when cold, it is a very tough material to machine and heavy on tools. So finished parts become very expensive.

"That is why the modern aerospace industry and additive manufacturers are meeting one another. AM offers easier manufacturing that is unencumbered by process limitations of the past. There is less waste, much less machining and it makes a huge amount of sense when designing for weight reduction," argues Vermeulen.

Part number reduction is also a key driver towards additive manufacturing: On a newly developed advanced turboprop engine from GE Aviation, for example, which is planned for use on Cessna and other small aircraft, by adopting additive manufacturing for 30% of the components, 855 parts were replaced with 12, resulting in lower assembly costs and lower operating costs with respect to inspection, handling, storage and supply. The engine is also lighter and more efficient.

Another example is the 3D-printed Fuel Nozzle for the new LEAP Jet Engine from GE, where 20 conventionally manufactured parts are now manufactured as a single unit by adopting additive manufacturing.

From a cost perspective, Vermeulen says that costs per part are coming down fast: "With the larger platform of the Aeroswift, the higher power laser and the faster scanning available from the mirrors and reflectors, the machine is six to ten times faster than currently available commercial systems. This brings costs per part down to one third of those being commercially quoted.

"And these costs are sure to drop as we downscale machines to match specific component requirements and cost scenarios," he adds.

"If South Africa can start producing lower cost titanium, we could be sitting with a global edge with respect to powder bed fusion technology. The potential is already big and it is going to get even bigger," Vermeulen believes.

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