Will composites be competitive with metals in 3D printing?

The composites industry has a tendency to get caught off-guard by metals as they make progress into more applications. 3D printing is an area where metals have taken the lead, but a number of developing technologies could put composites back on top.

MICHAEL CHAPIRO
CHIEF STRATEGY OFFICER
MANTIS COMPOSITES

Composites are often heralded as the materials of the future. Their strength properties offer an incredible advantage over any other material. With the Boeing 787, Airbus A350, and BMW i-series, composites are well on their way to establishing a stronghold in mainstream manufacturing. However, the metal industry is still very much a threat to the continued success and growth of the composites industry. Alcoa's 3rd generation of aluminium-lithium alloys has led many companies to move away from composites, and these alloys are slated for various new aerospace projects. Considering that it was only in the past few years that composites became viable in a large-scale performance production line, these forward leaps in metals could pose a threat to the increasing market penetration of composites.

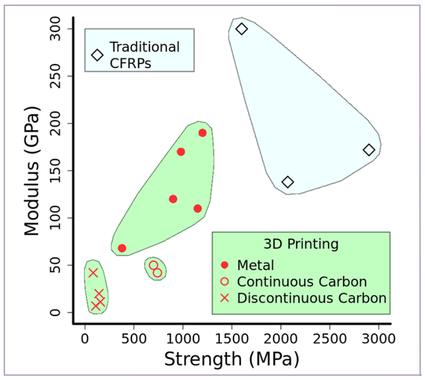

Fig. 1: Strength and stiffness of traditionnal composites compared to 3D printing

Metal 3D printing

3D printing is another area where metals compete with composites. Metal 3D printing already works fairly well for a variety of alloys, but by virtually any metric, there is currently no 3D printing technology for composites that is comparable in performance to the best that metal 3D printing has to offer, let alone something comparable to tape laying. Research in metal 3D printing has been ongoing for the past decade, leading to multiple advances with applications in aerospace and other industries such as high-performance automotive. Titanium 3D printers can currently achieve comparable properties to machined titanium when using a solid rod feedstock, and although these parts require some degree of post-machining, they are proving effective for intricate, high-strength parts. Selective laser sintering (SLS) printers, which use a powdered input material, eliminate this machining step making them precise enough to use in components such as fuel nozzles in CFM's LEAP engine, but the powder process has other drawbacks such as porosity.

A true carbon fibre 3D printer should be able to produce intricate, detailed, and strong parts greatly surpassing the capabilities of machined aluminium and 3D-printed metal at a cost that falls in between the two, all while easily producing highly tailored properties along with entirely new CFRP structures. Composite feedstocks are less expensive than the precisely powdered alloys used in some metal 3D printers, and the energy required to heat a thermoplastic or reactive polymer is much lower than the energy required to fuse metal. This goal has not yet been achieved due to limited investment in this area and engineering challenges rather than any inherent physical limitations.

Significant disadvantages

Several startups have developed various systems to 3D print composite materials over the past few years, but all the current approaches demonstrate significant disadvantages when compared to machined aluminium, especially for industrial applications. As a result, these startups tend to focus on either consumer 3D printing or merely providing geometric prototypes.

The material feedstock presents one of the major limitations. Markforged, the makers of the first carbon fibre 3D printer, is the only company currently offering a continuous fibre process. But researchers have shown that their filament has large voids and contains many resin-rich areas, resulting in substantially lower proper-

Focus

Mantis Composites, a startup company close to having the first carbon fibre 3D printer that can produce fully functional composite parts with continuous fibres in 5 axes, is currently seeking strategic partners and investors interested in the performance that could be realized with their solutions.

ties than the rule of mixtures would suggest – their unidirectional coupons just barely surpass 6061 aluminium in tensile strength. Plus, the combination of porosity and printing parallel layers rather than multiaxial printing results in poor interlaminar and fatigue properties leading to delamination and matrix cracking. Markforged has effectively targeted their product to the consumer market, offering a safer and more manageable alternative to CNC machining aluminium at home, but this solution (especially when considering the $500/lb+ price point for their filament) is difficult to justify outside of the home, workshop or makerspace.

Mechanical performance only gets lower from here. Enter discontinuous carbon fibre 3D printing, a process that currently yields low properties since the fibres are so short they pull out of the matrix rather than reinforcing up to fibre failure. The minimum length to have the fibre rupture rather than slip is known as the critical length. Although chopped carbon fibre feedstock is available for SLS applications, the powder morphology limits fibre length. Impossible Objects has developed a process that involves stacking layers of carbon fibre tissue-paper-like material, and pressing those together. This uses somewhat longer fibres, but it is expensive and achieves comparable performance to SLS.

Fused deposition modelling

Fused deposition modelling (FDM) printing could theoretically achieve longer fibre lengths, but all current solutions have fibre lengths about an order of magnitude lower than the critical length. Regardless, it is still an interesting area. Arevo Labs is one of the companies currently offering fibre-reinforced FDM with high-temperature thermoplastics. The current processes for making FDM filament are adapted from the same sort of screw extruders that are used for injection moulding, and this process always breaks down carbon fibres well below their critical length. Therefore, when Arevo adapted this process to the intrinsically stronger PEEK, they did get some improvement, but not enough to bring the true strength of composites to their parts. Arevo's parts have roughly double the tensile strength and four times the modulus of PEEK plastic alone. In comparison, Cytec's ACP-2 PEEK (intermediate modulus), a prepreg composite material commonly used for automated tape laying, has 40x the modulus and 30x the tensile strength of neat PEEK. That is a large performance gap. Arevo Labs uses a multi-axis robotic arm instead of a simple 3-axis printer, which allows them to develop parts more tailored to the strength needs of their customers, but higher mechanical properties are needed to achieve the full value of that system. Besides, their high cost (higher than Markforged) further detracts from use in a production setting.

Potential methods

However, there are still potential methods for higher performance 3D printing with short fibres. Given how short all the fibres are in these processes, any company that could develop a filament for FDM with high-temperature thermoplastics and carbon fibres with an average length closer to or above the critical length could achieve substantially higher properties at a reasonable cost, opening up many new opportunities.

Despite the current limitations, it is important that efforts are being made towards making carbon fibre 3D printing work. Large amounts of money are being invested into proven metal 3D printing technologies, but far less money is going towards developing the so far unproven concept of a true carbon fibre 3D printer. With metal 3D printing, existing companies are focusing on developing this cutting edge technology, whereas composite 3D printing advancements are coming almost entirely from smaller startups with disjointed approaches. Some of the approaches suggest paths towards improvement – short fibres can be made longer, multi-axis printing machines can be developed that target a low cost per print time for parallel manufacturing, and continuous fibres need to be effectively wet-out and oriented.

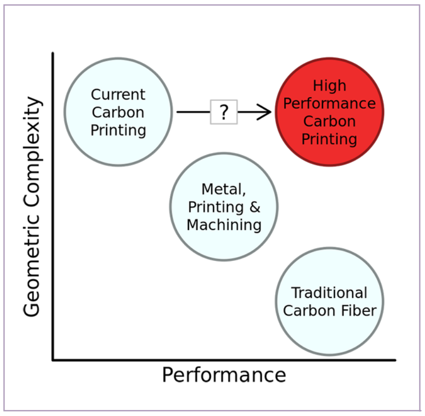

Fig. 2: Carbon fiber 3D printing could bring high performance and complexity

Sporadic effort

Incremental improvements are not what allowed the metal industry to develop the 3D printing technology they have – it was the significant investments into a technology that had the potential to be a serious game-changer. Alcoa's yearly revenue is roughly the same as the entire carbon fibre composites market, and their investment is focused, whereas the composite industry often makes sporadic efforts towards short-term objectives that do not usually span across the entire industry. The model of playing catch-up eventually works, but why not gain the definitive edge and maintain the lead? This can be achieved, to the benefit of the composites industry and its customers, by systematically engaging and pursuing new risky technologies, even if those technologies are not being developed in-house and still need maturation. Composites may very well be the material of the future, but 3D printing is the manufacturing method of the future, and until the two are combined in an effective, inexpensive, and scalable method, the ease of use presented by metal will continue to prevail. □

More information:
mchapiro@mantiscomp.com