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ADDITIVE MANUFACTURING: CHALLENGES, POSSIBILITIES, AND THE GEAR INDUSTRY

Additive manufacturing is a technology with a great deal of potential to affect the gear industry as well as manufacturing at large, but there are challenges for it to overcome if this impact is to occur.

ADDITIVE MANUFACTURING (AM) IS A technology that has the potential to fundamentally alter manufacturing, specifically metal manufacturing. The ability to design complex shapes, which could not otherwise be manufactured, coupled with a significant reduction in scrap metal, has obvious benefits. However, for all of the publicity that the technology has received, there are still several challenges that need to be addressed if AM is truly going to supplant traditional, subtractive manufacturing technologies.

WHAT IS ADDITIVE MANUFACTURING?

AM is a process whereby components are constructed directly from raw materials (typically powder or wire) in a controlled fusing process. As the name would indicate, AM, and specifically metal AM, is truly the antithesis of traditional forming operations such as grinding and milling. These subtractive technologies start with a "block" of material from which portions are removed until the final desired shape is produced; this type of process generates a fair amount of waste. There are also limitations on the complexity of shapes that can be formed by these operations as they are largely limited to "line-of-sight" alterations. As such, complex components have to be made in multiple pieces that are then joined together subsequently — adding more cost and time to the generation of a final component. As AM is a building process rather than a removing process, there are essentially no limitations on the complexity of the parts that can be built, and there is a significant reduction in wasted material.

METAL ADDITIVE MANUFACTURING TECHNOLOGIES

There are many different names and types of metal AM. The first differentiation of metal AM can be made based on the nature of the material that is being used — powder versus wire. Further differentiation is dictated by how the metal material is fused — laser versus electron beam. There are other differentiating factors in metal AM, but they become more nuanced. For this column, discussion will be limited to powder-based AM technologies as these technologies currently exhibit the greatest industry acceptance for "critical" (i.e., load bearing or dynamically utilized) components.

Typical Roughness Values based on Final Forming Step	
Final Forming Step	Average Surface Roughness (Ra)
Grinding	0.6 μm or ~24 μin
Isotropic Superfinishin	0.08 μm or ~3 μin
EBM	30 μm or ~1200 μin
SLM/SLS	15 μm or ~600 μin

Table 1

The majority of powder-based metal AM is in the form of powder-bed fusion technologies. Powder-bed technologies utilize a thin layer of metal powder and a movable "beam" element to build components layer by layer. The most prevalent of these technologies are EBM (electron beam melting), SLM (selective laser melting), and SLS (selective laser sintering). SLS is often incorrectly referred to as DMLS® (direct metal laser sintering), which is an EOS GmbH trademark.

EBM utilizes a heated vacuum chamber with a temperature just below the chosen metal's melting point and an electron beam to melt the metal powder. SLM and SLS typically utilize an ambient temperature chamber containing an inert gas such as argon and a high-powered laser to melt or sinter the metal powder. EBM tends to produce parts with better material properties, whereas SLM and SLS tend to produce parts with significantly better surface roughness and texture. It is worth noting that the average surface roughness of all powder-bed fusion processes will be significantly higher than those produced by typical subtractive manufacturing processes (see Table 1).

METAL ADDITIVE MANUFACTURING CHALLENGES

Metal AM has a number of challenges that it needs to overcome in order to make a significant impact in mainstream manufacturing. The foremost challenges are: build density, surface roughness/waviness and the "false/distressed" surface layer, and build consistency.

Build density refers to the actual material density of the final component and affects its tensile strength and bending fatigue characteristics. Build density is primarily affected by the speed that is used in the building process, whereby slower build rates with greater energy concentration during the building process will yield increased density. Many metal AM machine makers and machine users will claim to have 100-percent build density, but, in actuality, the as-printed build density is commonly less than 100 percent. The areas of porosity

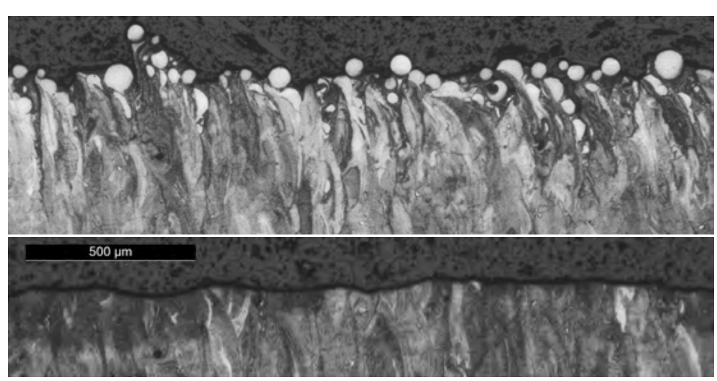

Figure 1: (Top) As-built cross-section of an EBM Ti 6-4 component; (bottom) the same component after isotropic superfinishing

are not uniformly dispersed; rather, they tend to cluster in areas with more complex features and near the surface of the component.

Surface roughness and waviness are significant issues due to the powder/layer-based building nature of metal AM. These issues are linked to the false/distressed surface layer that is produced by the manufacturing process. EBM, SLM, and SLS-produced components have a top layer that is made up of many partially sintered and melted particles. This layer is rife with microscopic voids and V-notch failure points and is not optimal for use straight off the printer (see Figure 1).

Build consistency is an issue with metal AM. Many factors influence the performance of a metal AM printer. Some of these factors are: build direction, build speed, building plate part density, and powder quality. Build direction determines the "weak" points of the component as bending fatigue will typically occur parallel to the build layers. Build speed, as mentioned, affects part density; it also affects surface roughness and the thickness of the false surface layer. The density of parts on the printer's build plate will affect build consistency as it will alter the heat dissipation between each laser or electron beam pulse. Lastly, build consistency is affected by powder quality. Metal AM powder should be perfectly spherical. However, incoming powder quality issues can result in misshapen powder. And recycled powder (i.e., powder that has already entered the build chamber) can become misshapen or fused.

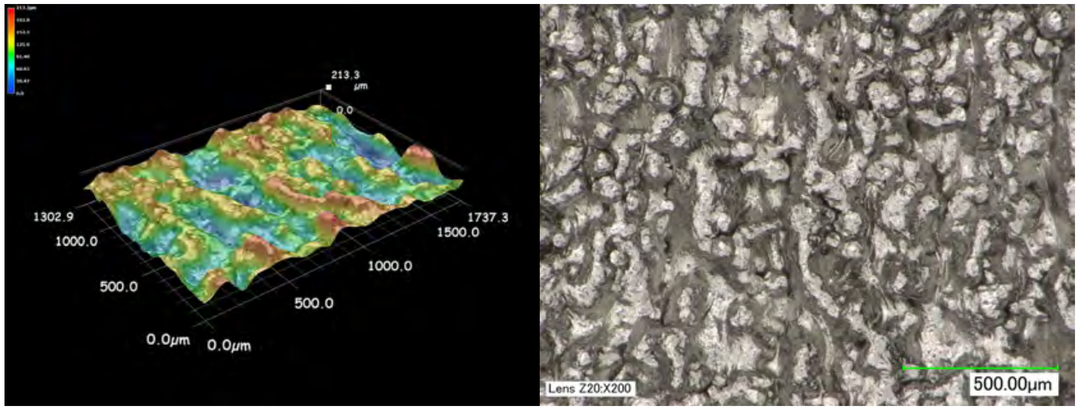

Figure 2: As-built EBM Ti 6-4 component

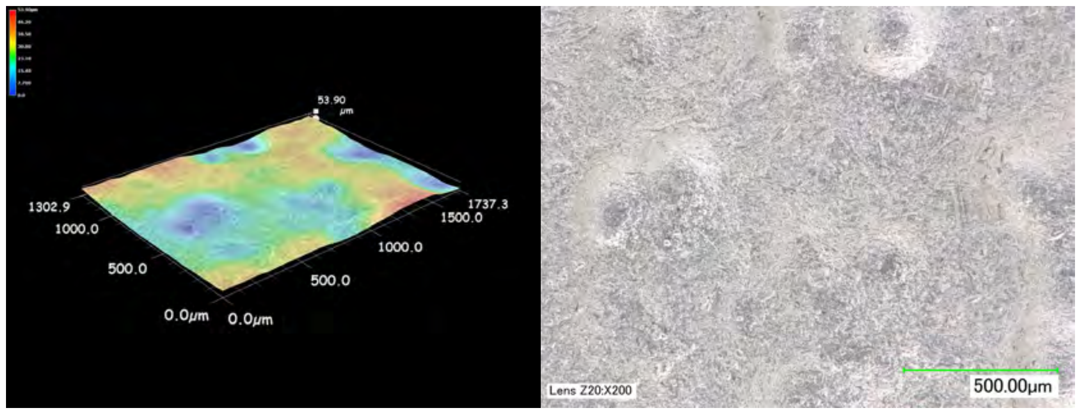

Figure 3: Isotropically superfinishing EBM Ti 6-4 component

POST-PROCESSING AND SOLUTIONS

Post-processing is the term that the AM industry uses to refer to all processes that are done after the printing is complete. The AM industry would like to minimize post-processing as it reduces its differentiation from multi-step subtractive manufacturing processes, but currently, some post-processing seems to be necessary if metal AM components are to be used in dynamic or critical applications. Prominent technologies include hot isostatic pressing (HIP), isotropic superfinishing, and machining.

HIP is essentially a highly pressurized heat treatment that has a goal of increasing part density for improved physical properties. The HIP process is effective, but it has its own range of parameters that influence its effectiveness. Isotropic superfinishing is a known technology in the manufacturing industry. It is effective at eliminating the false/distressed surface layer. If the process is properly designed, it is also effective in reducing the surface waviness of a component (see Figures 2 and 3). Machining is also a useful post-processing technology for addressing variations in final build shape. Hybrid machines are a growing trend in the AM industry where a metal AM building apparatus is combined with a milling machine. While the AM industry can have reluctance to make use of machining as a post-process, there is certainly logic to make use of it on certain part types.

Overall, these post-processing techniques in combination with robust building parameter controls can facilitate the production of parts that are suitable for many applications.

METAL ADDITIVE MANUFACTURING AND GEARING

There is little doubt that gears will be made via AM in the future. Currently, the available build materials are a strong limiting factor in making AM gears — namely, that few steel options exist. It would perhaps make the most sense for hybrid manufacturing to be the first entry point for AM gearing, and certainly, some of the aforementioned post-processing techniques will be required.

In conclusion, metal AM is an exciting technology. It has challenges that need to be addressed, but one can already see solutions in place for some of these challenges in the various post-processing technologies discussed. One would expect these technologies as well as metal AM itself to continue to advance, thereby increasing the viability of metal AM in gearing and manufacturing in general. While it is unclear if AM will ever fully replace subtractive manufacturing technologies, it seems fairly certain that it will, in the long run, claim a significant portion of the manufacturing market.

ABOUT THE AUTHOR: Justin Michaud is the CEO of REM Surface Engineering, a leader in the metal finishing industry for over 50 years. Michaud's expertise is in lean manufacturing, operational and financial management, and strategic planning. He is a graduate of the University of Notre Dame's Mendoza College of Business where he was a member of the university's men's soccer team. He can be reached at jmichaud@remchem.com.