Relevance of new AM developments for AM Supply Chain in terms of Powder Supply

Introduction

A supply chain is a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer. Supply chain activities involve the transformation of raw materials, resources and components into a finished product that is delivered to the end customer [1]. In sophisticated supply chain systems, used products may re-enter the supply chain at any point where residual value is recyclable. Modern consumers are expecting to receive their orders sooner than ever before. The digital marketplace continues to expand beyond the traditional retail business model every day and consequently, customer expectations grow. This has changed the way that supply chain professionals must work to ensure orders are processed and fulfilled.

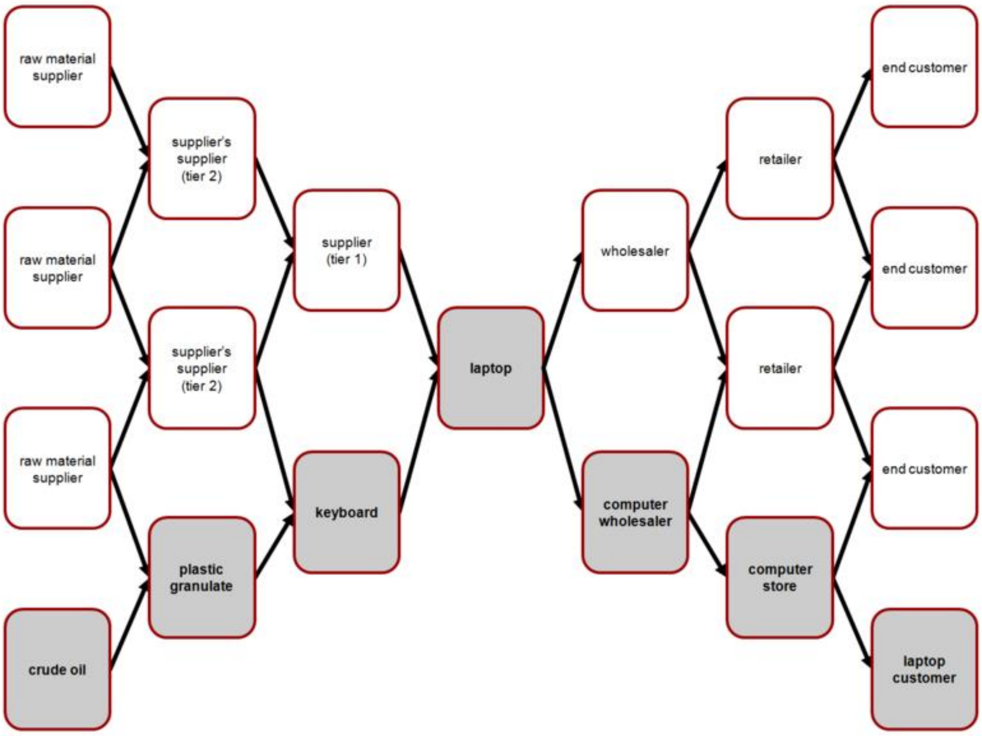

Figure 1: A typical example of a supply chain for a laptop computer [2]

A typical supply chain (Figure 1) begins with the ecological, biological, and political regulation of natural resources, followed by the extraction of raw material, and includes several production links (e.g., component construction, assembly, and merging) before moving on to several layers of storage facilities of decreasing size and increasingly remote geographical locations, and finally reaching the consumer. Many of the exchanges encountered in the supply chain are therefore between different companies that seek to maximize their revenue within their scope of interest but may have little or no knowledge, or interest in the remaining players in the supply chain. Shortly, a chain is actually a complex and dynamic supply and demand network.

Additive manufacturing, which is known as 3D printing, turns digital 3D models into physical objects by building them up in layers. This technology enables small quantities of customized goods to be produced at relatively low costs. 3D printers are used in several and diverse industrial sectors, such as automotive, health-care, aviation, clothing and even in foodstuff. 3D printers give, in fact, the opportunity to manufacture several products, from replacement parts to dental crowns, artificial limbs. The method is seen as a disruptive technology for supply chain management because of its characteristics. Holmström et al. [4] highlight the following benefits of AM methods over the conventional manufacturing methods as:

- No tooling required
- Feasibility of producing small production batches in an economical way
- Possibility for quick changes in design
- Product optimization for functionality
- More economical custom product manufacturing with the capability to produce complex geometries
- Potential for simpler supply chains with shorter lead times and lower inventories

In addition to above benefits, there is the possibility of reducing material waste by as much as 90% according to a report by Markillie [5] on AM. Traditionally, raw materials or components are supplied from suppliers, assembled in manufacturers and shipped to customers through retailers or distribution centers. On the contrary, Additive Manufacturing technology enables organizations to bypass the traditional supply chain and manufacture a product themselves with a digital design (Figure 2).

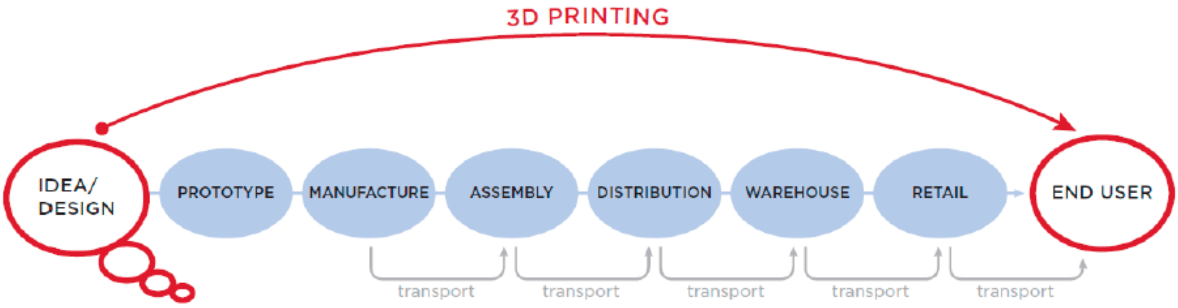

Figure 2: Traditional versus AM supply chain [3]

Nowadays, many companies integrate AM Technology into their supply chains. The average annual growth rate of worldwide revenues produced by all products and services over the past 30 years of Additive Manufacturing is 26.7%, where the growth within the four years from 2016 to 2019 is more than 23%. The Wohler’s report states that the total AM industry achieved a size of $12.7 billion by the end of 2020, and according to Lux Research from Boston-USA, the value of additively manufactured parts is to rise at a 15% compound annual growth rate (CAGR) from $12 billion in 2020 to $51 billion in 2030. AM is a growing means to produce both prototypes and products.

Powder Supply Chain

The production of AM metal powder generally consists of three major stages as outlined in the flow diagram shown in Figure 3. Briefly, the first stage involves the mining and extracting of ore to form a pure or alloyed metal product (ingot, billet and wire) appropriate for powder production; the second stage is the production of the powder and the final stage is classification and validation. The supply chain of taking ore and extracting a metal is well established and supplies a vast range of pure metals and specific alloys to global markets.

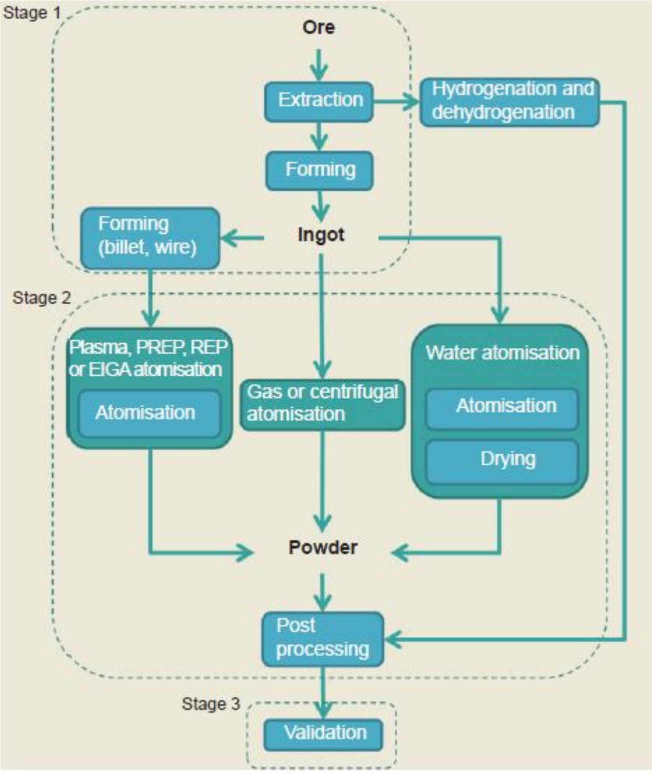

Figure 3. Powder production steps flow chart from ore to validated AM powder [6]

Once an ingot of the metal or alloy has been formed, a number of additional processing steps may be required to make the feedstock suitable for the chosen atomisation process. For example, plasma atomisation requires the feedstock material to be either in wire form or powder form, thus adding additional rolling and drawing work or a first step powder production route.

Manufacturing Process	**Particle size, µm**	**Advantages**	**Disadvantages**	**Common uses**
Water atomisation	0–500	High throughput Range of particle sizes Only requires feedstock in ingot form	Post processing required to remove water Irregular particle morphology Satellites present Wide PSD Low yield of powder for 20–150 µm	Cu, Al (Non reactives)
Gas atomisation	0–500	Wide range of alloys available Suitable for reactive alloys Only requires feedstock in ingot form High throughput Range of particle sizes	Satellites present Wide PSD Low yield of powder between 20–150 µm	Ni, Co, Fe, Ti, Al
Plasma atomisation	0–200	Extremely spherical particles	Requires feedstock to either be in wire form or powder form High cost	Ti (Ti64 most common)
Plasma rotating electrode process	0–100	High purity powders Highly spherical powder	Low productivity High cost	Ti
Centrifugal atomisation	0–600	Wide range of particle sizes with very narrow PSD	Difficult to make extremely fine powder unless very high speed can be achieved	Solder pastes, Zinc of alkaline batteries,
Hydride–dehydride process	45–500	Low cost option	Irregular particle morphology High interstitial content (H, O)	Ti6/4

Table 1 : Powder Characteristics by Manufacturing Processes [6]

As mentioned above, there are a number of methods available to produce metal powders including such as solid-state reduction, electrolysis, various chemical processes, atomisation and milling. Historically, for reasons rather commercial, atomisation has been identified as the best way to form metal powders for AM regarding the geometrical properties of the powder it yields. Table 1 summarizes powder characteristics obtained by different manufacturing processes.

Importance of Particle Size and Morphology

Particle morphology has a significant impact on the bulk packing and flow properties of a powder batch. Spherical, regular, and equiaxed particles are likely to arrange and pack more efficiently than irregular particles. Research into the effect of particle morphology on the AM process has shown that morphology can have a significant influence on the powder bed packing density and consequently on the final component density; where the more irregular the particle morphology, the lower the final density. As a result of this, highly spherical particles tend to be favoured in the AM process. Figure 4 shows various morphologies of iron powder achieved by different production methods.

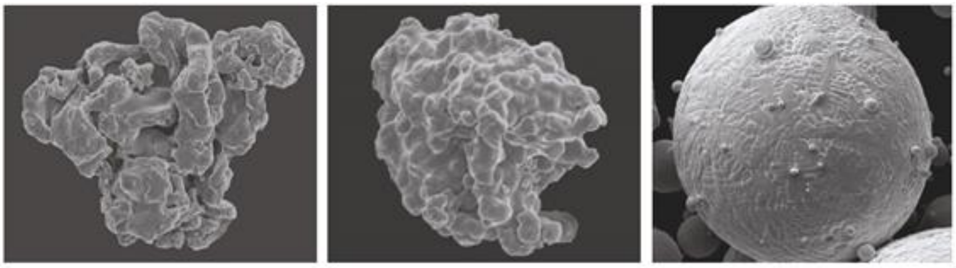

Figure 4: Examples of powders with different morphologies. [8]

The particle-size distribution (PSD) is a list of values or a mathematical function that defines the relative amount of particles present according to size. It can offer the information regarding the particle size span width, and D10, D50, and D90 (as known as D-value or three-point specification) is the most widely used values in PSD analysis. Those values indicate the particle diameter at 10%, 50%, and 90% of the cumulative distribution. Characterisation of Particle Size Distribution (PSD) in a batch of powder ensures that the optimum range of particles, by size, are used in each process.

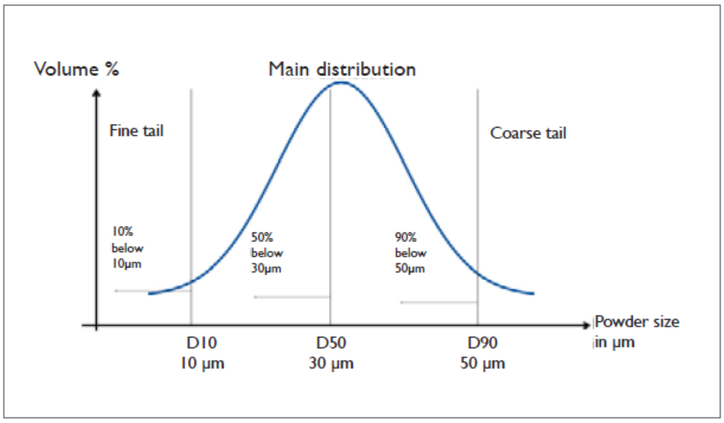

Figure 5: Example of D10, D50 and D90 on a PSD curve for a 10-50 microns powder

In general, Electron Beam Melting uses a nominal PSD between 45–106 µm, whilst L-PBF uses a finer range between 15–45 µm, and Binder Jetting between 5–30 µm. PSD will have an obvious impact on both the minimum layer thickness and the resolution of the finest detail in the component.

An inappropriate combination of PSD and layer thickness can potentially lead to in situ segregation due to the mechanical re-coater pushing coarser particles away from the bed, segregation in this sense could lead to variation in build quality in the vertical direction. It is generally well reported that using powders with a wide PSD and a high fine content produce components with a higher fractional density. However, the use of fine materials increases the risk of health and safety issues. This is particularly true when processing reactive materials such as titanium where finer particulates are likely to be more flammable and explosive. In 2011, a terrible accident took place at Hoeganaes facility in Gallatin, USA with 3 injuries and 5 deaths, due to an explosion of fine metal dusts at nanoscale that were piled up in various areas of production [7].

Impact of AM

Powder flowability is an important technological requirement for powders used in AM. The density homogeneity of the final part depends on the layer-by-layer melting being performed on thin and uniform layers that are accurately deposited by the feeding device. Cohesive powders which exhibit poor flow properties are likely to be more problematic in terms of obtaining homogenous density layers throughout the build than powders which are comparatively more free flowing. Powder flow is difficult to relate to any one given parameter of a powder but there are some general rules which can typically be applied:

(a) Spherical particles are generally flowing better than irregular or angular particles

(b) Particle size has a significant influence on flow. Larger particles are generally more free flowing than smaller particles

(c) Moisture content in powders can reduce flow due to capillary forces acting between particles

(d) Flow properties often show a dependency on the packing density at the time of measurement – powders with a higher packing density are less free flowing than powders with a lower packing density

(e) Short range attractive forces such as van der Waals forces, electrostatic forces and humidity can adversely affect powder flow and may cause particle agglomeration (short range forces have a bigger impact on finer particles)

Although spherical particles with a good flowability are considered to be the most effective ones for AM, as different technologies of AM evolved within the recent years, each one has come out with different requirements of particle size distribution, as mentioned above.

Conclusions

Using additive manufacturing in the supply chain brings in many advantages in comparison to conventional manufacturing methods. There is less room for human induced error in the supply chain with AM. This results in a ‘first time right’ production with a lower lead time. Direct shipping becomes an option in the supply chain with AM, and manufacturers can reduce their dependency on different suppliers.

AM drives in decentralized manufacturing, where logistics companies will no longer have to transport finished goods though the globe. However, the last mile delivery of products will increase. Companies need to be agile enough to counter disruptions of this magnitude. The Logistics provider in fact becomes a manufacturer within this new world.

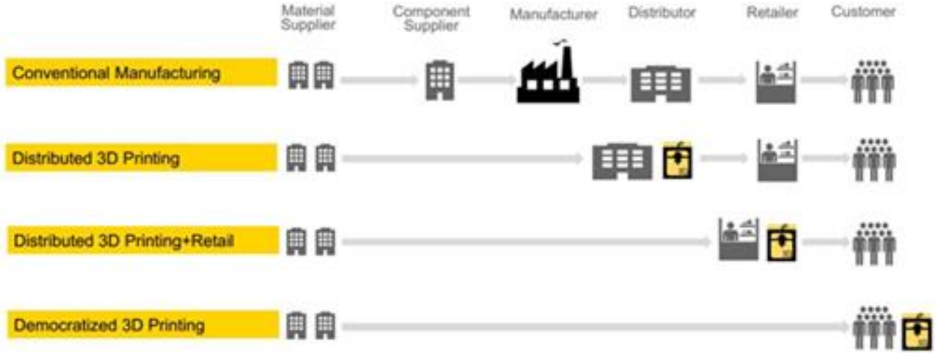

Figure 6 : AM at various levels in the supply chain [9]

AM is definitely creating a brand-new market for powder suppliers, but on the other hand, AM requires more strict qualifications of material supply in terms of metal powders. This narrows the band of usable powder in an ordinary powder production, making the efficiency decrease in comparison to production of powders used in conventional methods such a Press & Sinter. Because of this, price per kilo of powder for the AM market is much higher than the price for the traditional PM market. According to a past report by Roland Berger, increased competition for powder supply reduces today's markups and increasing production volume reduces costs. As an example, steel powder price for AM in 2013 that was more than 90 Euro/kg on average, has dropped down to less than 50 Euros/kg in 2021, which is actually still expensive more than twice the price of the conventional steel powder. As AM industry gets mature, material prices will settle down to reasonable values in the market.

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If you are interested in learning more or engaging in developing skills in Additive Manufacturing mentioned above, please get in contact with us through the website: http://skills4am.eu/contact-us.html

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