2.3.2 Generation from the Solid Phase

2.3.2.1 Melting and Solidification of Powders and Granules – Laser Sintering (LS)

Powders or granules arranged in a powder bed are source materials for the formation of a solid layer whereby layer surfaces are melted together by a laser beam. Such processes are called sinter processes because the deliberate melting resembles a classical diffusion-controlled sinter process.

The term "sintering" derives from powder metallurgy and describes a procedure in which powdered material under high temperature and high pressure over a relatively long period of time is "baked" in a mold into a solid shape. The tabletting as well as the long processing time are characteristic dimensions. Sinter processes are used in powder metallurgy when:

- The high temperature of the molten mass makes other production processes uneconomical (Wolfram filaments of bulbs)
- A certain porosity is required (dry running properties of friction bearings)
- Alloy constituents are to be realized that in the molten state would segregate completely or partly (pseudoalloys)

Selective Laser Sintering

In the classical understanding of sintering under high temperature and high pressure two neighboring particles are linked to one another at a contact point first in the form of a neck, which is formed by the mechanism of surface diffusion. With the progression of sintering, over a longer period of time under the combined influence of temperature and pressure, material is transported especially along the particle boundaries and inside the sintering particles (particle boundary or volume diffusion)

The laser sintering used as a rapid prototyping process functions to the exclusion of the two fundamental components of the classical sinter process, pressure and time. Only a short thermal activation of the particles to be sintered takes place.

The particles lie loosely in the powder bed. They are made molten on the surface locally (selective) by a laser beam and thereby joined to a layer. In fact this is a partial melting and solidification process known as liquid sintering or (selective) laser sintering.

Because the classical conditions of high pressure and long contact time are, as previously mentioned, not required for laser sintering, it must be assumed that the laser sintering process is not or is not dominantly diffusion controlled, but that it is in fact an incipient melting or even a fusion of powder particles.

The laser sintering process exploits the fact that powder has a greater surface area than solids and that every physical system strives to minimize its energy state. Consequently in neighboring particles that are incipiently molten on the surface the total surface is minimized by fusing of the particles' outer skins.

The sinter process is best described as the interaction between the viscosity of the incipiently molten particle areas and their surface tensions. Both the counter effects are functions of the temperature and the material.

Materials for Selective Laser Sintering

In principle, all materials that can be melted and, after cooling, solidify again (as far as possible with a constant volume) can be used for the sinter process. Because – in contrast to the classical sinter process – the parameter pressure and temperature have to be kept very low only plastic material and wax were sintered at first mainly owing to their low melting points.

Plastics Powder

The low temperature range of up to approx. 200 °C favors the sintering of plastic materials. The low heat conductibility is also advantageous. It helps to limit the melting bath locally and to prevent the "growth" of models by neighboring particles being sintered on. Although the surface tension of the molten mass – low compared to that of metals – impedes the sinter process it fosters the wetting of the model, thereby minimizing the danger that macroscopic globules are formed and separated from the layer.

Crystalline and amorphous plastics behave completely differently. The vast majority of materials (metals included) solidify crystalline. Their elementary particles, atoms or molecules, are set in defined regular spatial crystal gratings.

Glass, resin, or pitch solidify amorphous (i.e., with no fixed structure). Although their elementary particles are also practically stationary they possess no recognizable defined structure. Physically they should be considered as an undercooled molten mass. The effect of devitrification is well known: an unwanted crystallization causes amorphous transparent glass to crystallize and become opaque.

Amorphous plastics are characterized by a broad temperature range within which they soften or convert into another state of aggregation without sudden alterations to their mechanical-technological properties (Figure 2-22a). Crystalline plastics change their state of aggregation and thereby all important mechanical-technological properties in such a narrow temperature range (often only 1/10 °C) that it is called a "melting point" (Figure 2-22b).

The basic properties of these materials are decisive for the behavior of models during the build process (shrinkage) and for the achievable properties (solidity) of models.

Polyamide (nylon) belong to the most often used sintering materials which are crystalline whereas polycarbonate and polystyrene are amorphous plastics.

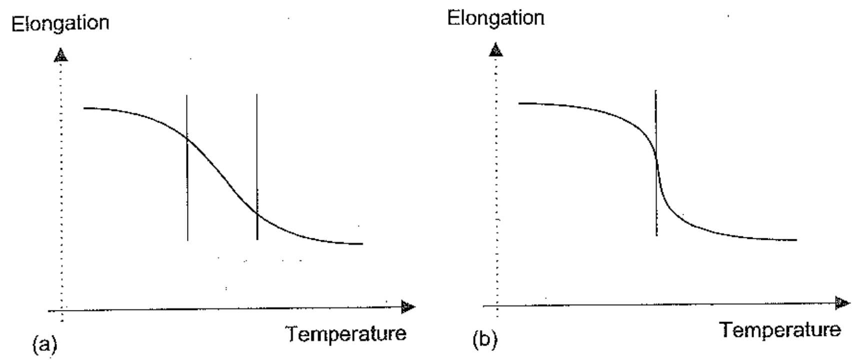

Figure 2-22 Physical properties of (a) amorphous and (b) a crystalline plastics, schematic

Multicomponent Metal-Polymer Powder

The first step to sintering metal powders is made via polymeric-linked metal powder. The process is fundamentally therefore not very different from the fusion of plastic powders. The polymeric shells are sintered on and "glue" the integrated metal particles together to form a so-called green product.

In a second step, the polymeric particles are expelled by heating while in a third step they are infiltrated with a low-melting metal (e.g., copper) in an oven (with reduced atmosphere). This process makes high demands on technology and installations.

From the viewpoint of sinter theory the process belongs to the category of plastic sinter processes.

Basically, all materials can be processed in the same manner in plastic sinter machines. Polymeric-linked sands, ceramics, and the above-described metals are technically realized.

Multicomponent Metal-Metal Powder

When low-melting metal powder – instead of polymeric binder – is mixed mechanically with the high-melting component, the process becomes safer and faster. The binder function is then taken over by the low-melting component. The mechanical-technical properties of the model, however, are very different from those of currently used series alloys. These models can therefore be used only to a limited extent as functional models. Figure 2-23 shows the basic interrelationships of polymeric linked powders and of multicomponent powders in the sintering process.

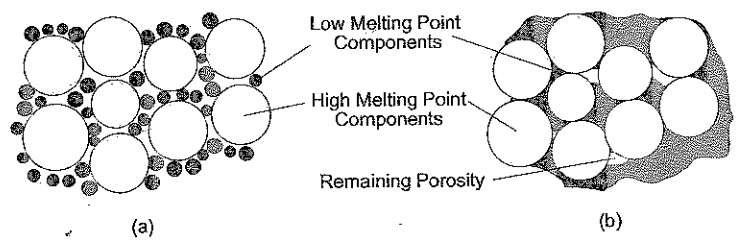

Figure 2-23 The principle of liquid sintering (FHG-ILT)

Single Component Metal Powders

At first the sinter process was used for plastic materials owing to relatively low process temperatures and poor heat conduction, which locally limits the reaction zone; now, with a modified process control, metals are also suited for laser sintering. In their melted state they have a higher surface tension and a lower viscosity than plastic materials. The driving force hereby is the surface tension while the opposing force is the viscosity, both of which are more favorable than with plastic materials. However, the process temperatures and therefore the constructive complexity are much higher. Such developments are the subject of worldwide intensive research, especially at the University of Texas (Austin), at the Fraunhofer-Institut für Lasertechnik (ILT) (Institute of Lasertechnology, Aachen, Germany) and Produktionstechnologie (IPT) (Institute of Production Technology, Aachen, Germany) and at the Fraunhofer-Institut für Werkstoff- und Strahltechnik (IWS) (Institute of Material and Beam Processing Technology, Dresden, Germany). In principle two paths are followed: the direct sintering of metallic materials according to the process of selective laser sintering described previously, and laser-supported generation derived from the classical coating process. The aim is the treatment not only of metals but also of ceramics. The characteristics of these processes, their current status, and the development trends are discussed in detail in Chapter 7. At the end of 1998, EOS presented a single-component metal powder for its machines (see Section 3.3.2.3) which produce metal prototypes with properties comparable to those of foundry steel.

Advantages of Laser Sintering

The linkage through thermal influence by laser beam gives selective laser sintering a far greater and possibly even an unlimited choice of materials in comparison to stereolithography. The resulting models are, depending on the material, mechanically and thermally resistant. In many cases they attain the status of functional models.

Powder that has not been sintered can be recovered and used again.

It is basically a one-step process. Further crosslinkage is not necessary. Supports are not needed.

For cleaning purposes (theoretically) only a brush and a sand blaster is needed. Solvents are not required.

The models are immediately ready for use.

Disadvantages of Laser Sintering

The achievable accuracy of the model is basically limited by the size of the powder particles. The material and its absorption properties and its heat conductibility define the possible build speed and the necessary laser power.

The models tend to "grow" depending on the relationship of "applied power" and "conductibility," that is, neighboring particles in the powder bed not belonging to the model are glued on by heat conduction and the model grows a "fur."

Internal hollow spaces are more difficult to clean than with stereolithography. It is unavoidable that loose or only slightly glued particles remain on the model. These particles impair accuracy and could possibly detach themselves at inconvenient moments when the model is later used. These components therefore cannot be sterilized for medical use in operating theaters.

To avoid oxidation, the sinter process takes place within an inertgas (nitrogen) atmosphere.

Because the sinter process takes place at near melting temperature, the entire powder bed needs to be preheated evenly to near this temperature to achieve an efficient sinter process. The temperature must be kept within restricted limits (a few degrees centigrade). The heating and cooling processes are very time-consuming.

2.3.2.2 Cutting from Foils – Layer Laminate Manufacturing (LLM)

The most simple method of producing 3D models is to split them into 2D contoured layers, to cut these layers out, and then to assemble them into 3D models. This is no longer a purely additive process. Bernard's precise term for all rapid prototyping processes which, in addition to the purely additive steps also include denuding (milling) or separating (cutting) steps, is subtractive/additive processes [BER98]. We will not follow this refined terminology, as the discussion here is focused primarily on the generation of models from layers; in practice scientifically exact, refined terminations do not enlighten further.

Layer models are known through the rib constructions of ships or the contour line models in geodesy. To obtain sufficiently detailed models, the layers must be very thin and exactly positioned to one another. Therefore, in most processes, the new layer is first glued to the preceding one, that is, onto the already finished part of the model; only then is it contoured. Layer model-making processes are known as layer laminate manufacturing (LLM). More common is the term laminated object manufacturing (LOM). This is not a generic term but a registered trade name which in this way became a synonym for the entire family of models (see also Chapter 3).

Lasers are very commonly used for contouring. Hot-wire cutters, knives, and milling machines are also used. Especially when contouring by milling machine the layers – in addition to being glued together – are also pinned together over center holes contained in the contour.