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A Review on Materials and Working Process Parameters of Selective Laser Sintering

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Abstract

The potential for additive manufacturing technology to replace some of the current conventional manufacturing methods makes it one of the research and development fields that is expanding quickly. With additive manufacturing, three-dimensional physical models are produced layer by layer from computer-aided design (CAD) models. Fully dense metal things may be produced more rapidly and accurately with additive manufacturing. The Selective Laser Sintering (SLS) procedure uses powder bed fusion, in which each layer of the powder bed is precisely fused by an electron or laser beam. The additive manufacturing method has the most potential for generating smaller and medium-sized quantities of either simpler or more complex metal objects. The process parameters directly affect the amount of energy delivered to the thin layer's surface and the energy density absorbed by the powders, which in turn determines the physical and mechanical properties of the built parts, such as relative density, porosity, surface roughness, dimensional accuracy, strength, etc. This analysis of the parameter-property connection is carried out for the most researched oxide ceramic materials, which include various ceramic mixtures and the alumina and silica families. One of those factors that is essential for improving ceramic quality is reducing temperature gradient, which minimizes thermal stress. The history, condition, and difficulties of the SLS Technique are discussed in this paper. The essay focuses on how the SLS technique handles metal materials. It also discusses the materials, equipment, and applications of the SLS processes, as well as their benefits and drawbacks.

Keywords: CAD Models, additive manufacturing, rapid prototyping, direct metal laser sintering (DMLS), SLS

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INTRODUCTION

By heating powered materials with heat produced by a laser (CO2) inside the hardware system, the SLS method fabricates 3D things layer by layer from CAD files. The SLS hardware system is where CAD data files in the STL file format are originally exchanged before being cut. Direct Metal Sintering (DMLS) is quite similar to the procedure [1]. The materials are totally melted rather than sintered in SLM, allowing for varied features including crystal structure and porosity. SLS utilities a similar idea [2]. By layer-by-layer solidifying materials that are comparable to powder and exposing the powder bed's surface to a laser or other high intensity beam, the technique known as laser-sintering helps create solid components [1-3]. Extremely quick sintering and solidification are characteristics of the laser sintering technique. SLS is the main topic of attention in this essay. Prospects for the quick production of metal components for use in arange of applications look bright for the SLS process [3]. Metal powders are the only component of SLS devices like Direct Metal Laser Sintering (DMLS) [4]. The process of ball milling is typically used to create powders, along with other techniques including fluidized beds, blades, brushes, etc. The procedure used in laser sintering techniques is as follows: after a part is designed, it is cut into horizontal slices using the necessary software [5]. A laser solidifies the powder as it passes over it, forming a thin coating of substance. Layer after layer is added until the part is complete, working from bottom to top (Figure 1) [6]. There is no waste since the leftover powder can be used again. Numerous laser-forming procedures are frequently referred to as SLS. SLS and SLM are sometimes distinguished from one another due to differences in the bonding mechanisms used in the two solidification processes [4-6]. In contrast to laser-sintering, which liquefies just the powder's surface to form links between the particles, laser melting includes totally liquefying the powdered material to generate a fully dense component. There is a lot of confusion between the terms "laser-sintering" and "laser-melting" [6, 7].

LITERATURE REVIEW

SLS and RP in general have lately acquired acceptance as the mainstream manufacturing method for mass-producing functional parts. However, there is very little published research on the connection between the component form, process variables, and energy consumption in the SLS process [8]. Research has often focused on the mechanical, chemical, and physical changes entailed in the formation of slices in various RP processes. J P. Kruth et al. [9] developed a modular system that was put into use to discover the best positioning of the CAD component quality model in the manufacturing process using a general algorithm technique. Diego Manfredi, et al. [10] employs a multi-criteria objective function to determine the ideal part orientation. These requirements include the anticipated construction time, the post-processing time, and the component's average surface roughness. Bin Qiana, et al. [11] investigated the SLS process and produced a thermal model in one dimension. To estimate the amount of laser energy needed to completely sinter bisphenol-A polycarbonate powder [12]. They investigated the impact of several parameters, including the temperature of the powder bed, the powder size, the laser scan speed, and the laser power on the formation of the sintered layers. To optimize the SLA process, Vennilaa. D B et al. [13] used a genetic algorithm (GA) method. They did this by evaluating the dimensional flaws in SLA parts and correlating them with the laser power used to make the slices. King, D. and Tansey, T [14] estimated the life cycle energy use in three RP processes: SLA, SLS, and FDM and investigated the environmental consequences of these processes [14]. However, no systematic research has been done to identify the best process variables for the SLS process to use the least amount of laser energy [15]. To analyze how much energy is used during the SLS process, Seyed Shirazi et al. [15,16] modelled the virtual manufacturing of a part and connected the energy to the slice thickness and part orientation. This publication's research is an attempt to move in that direction [17].

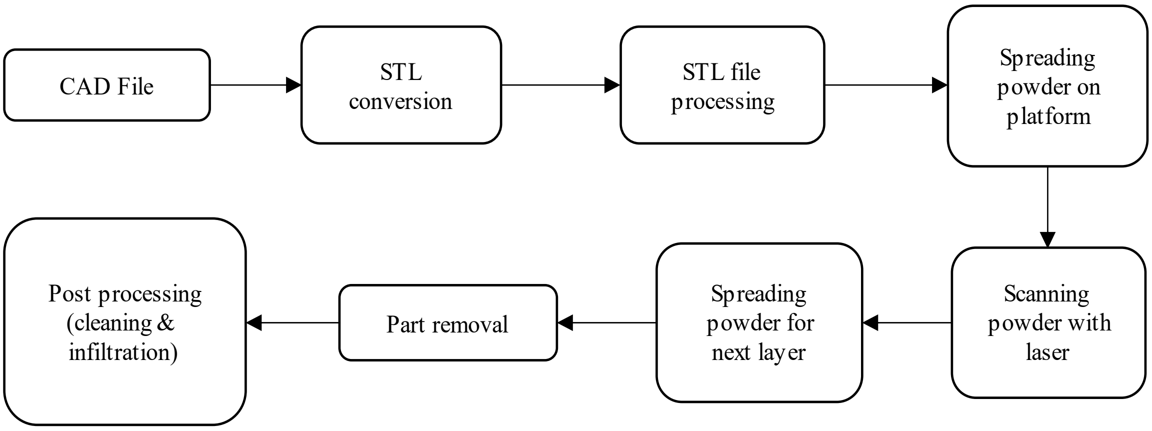

Figure 1. Process description on selective laser sintering (SLS) process [6].

Why Selective Laser Sintering Is Used (SLS)

SLS was developed as a manufacturing technique to reduce the length and cost of the design to product cycle, much like other AM technologies. The advantage of the SLS technique is that it can handle numerous applications throughout the manufacturing process by using a wide range of metals and materials [18]. Conceptual models, practical prototypes and pattern masters were their three principles early applications. They have since introduced a further module that includes raid tooling. Given the high cost and significant direct investment of interstation devices. They focused on huge manufacturing sectors that could manage such requirements as their target market [16-18].

Utilizing Materials in Selective Laser Sintering (SLS)

Nylon/polyamide (PA), polystyrene, elastomer, and composites are among the thermoplastics that may be manufactured with the SLS process [19]. The resolution and surface roughness of new nylon powder grades like Dura form PA12, Fine Polyamide, and PA2200 are even comparable to those of polycarbonate, making PA suitable for silicone rubber and epoxy mould casting [20]. Other polymer-based materials for investment casting include acrylic styrene and an easily obtainable elastomer for rubber-like uses [19,20]. Recently introduced on the market is Wind form XT, a carbon-filled PA that produces black components with a shiny appearance and a smooth finish. There are just a handful of unique SLS treatment formulae available right now, and nearly all of them are based on polyamide 12 (PA12) [21]. A comprehensive overview of the PA12 varieties that are now most common on the SLS market is shown in Table 1 [21]. This procedure may be utilized to create functional components from a broad variety of thermoplastics, composites, metals, and ceramics. And the powders are typically made either by atomization or ball milling. A few SLS machines utilize electricity from a single component. However, the majority of SLS machines typically just have two components: coated powder or a powder combination. [21, 22]. In single component powers, the laser only causes surface melting of a certain region of the power particle's outer surface [23]. SLS is an additive manufacturing process that may produce objects from a reasonably wide selection of powder materials that are easily accessible on the market by joining the previous layer and the solid, non-melted cores together. These materials include green sand, alloy mixtures, composites, metals like steel and titanium, polymers like nylon or polystyrene, and metals like nylon or polystyrene (Table 1) [21] There are three types of physical processes: complete melting, partial melting, and liquid phase sintering. Depending on the material, densities of up to 100% are possible while maintaining material properties comparable to those produced using conventional manufacturing techniques [22-24].

Table 1. Materials used in SLS and their properties [21].

Materials use in SLS	Materials properties
Alumide	1. It is a mixture of aluminium and polyamide. 2. Imparts a metal look to the component. 3. Parts are temperature resistant (up to 100^0C)
Polyamide	1. It can be used as a final part. 2. Highly resistant to chemical and durable. 3. It can be fused at lower temperature.
Polycarbonate	1. Mostly used investment and sand-casting patterns manufactured by SLS. 2. Needs less laser power to sinter.
Nylon	1. Highly durable thermoplastic material
Thermoplastic Elastomer	1. Imparts good surface finish. 2. Highly impermeable to water.
Metals	1. Need more sintering temperature. 2. Metal powders are sintered to get final components. 3. Inert atmosphere is required for reactive metals (Al, Ti and Stainless steel).
Ceramics	1. Zircon and silica are widely used. 2. Require more temperature for sintering.

Table 2. Shows the stages of the process parameters which were selected [25].

Process parameters	**Stage-I**	**Stage-II**	**Stage-III**
Slice thickness in mm (A)	0.02	0.06	0.09
Part orientation in degrees (B)	0	45	55

PROCESS PARAMETERS IN SELECTIVE LASER SINTERING (SLS)

Process parameters (a) laser-related parameters (laser power, spot, pulse length, frequency pulse etc. (b) Scan-related parameters, including scan spacing scan speed, and scan pattern. The full densification of the powder in each layer is the aim of some direct laser manufacturing techniques, including DLF, LENS, and DMD. SLS can create intricately formed metal parts with part densities that are more than 92 percent of the theoretical density [24,25].

Selection of Process Parameters in SLS Process

Numerous fabrication settings must be set up in the software before beginning to produce SLS items [26]. These parameters are set individually in accordance with the needs of applications to get the best quality. The initial step in the experiment was to identify the process control factors that are most likely to influence the laser energy in the SLS process. According to (Table 2) [25], there are three levels at which the two process parameters are chosen [24-26].

One such technique for quality improvement that incorporates quality into products and processes is experiment design, which does away with costly controls and inspection. It is a useful tool to accelerate the development cycle, lower development costs, and optimize product and process design [27,28]. Additionally, it will make the process of moving products from the R&D stage to production easier (Table 2) [25].

Pros and cons of technical process parameters of SLS

SLS distinguishes itself by producing parts from materials like nylon and titanium, which are normally challenging to produce using conventional techniques. No additional materials are required because the powder itself acts as the support material throughout the SLS procedure [29]. The post-processing of the created part takes time and involves the use of machining. There are few materials utilized in processing [29,30]. Even so, SLS metal parts only have a small amount of industrial use. Aluminum of the aerospace grade as well as other metals are being developed [31]. By calculating the amount of energy necessary to melt a unit of volume, the value of Ec for the SLM process has been established. In other words, the energy needed to change a powder from a solid to a liquid, with the lower bound being the melt enthalpy [32].

$$EEcc = \rho\rho\ [(TTmm - TT0) + LLmm] \qquad (1)$$

The average surface roughness is as follows:

$$Ra = f\ (P, V, PD, h, Ec) \qquad (2)$$

In this model, the average surface roughness and SLS/SLM conditions are mathematically connected. Using the power-law formulation, Ra may be described as follows: (3) The exponents in Eq. 3 are found using dimensional analysis (Table 3) [32,33].

$$RRaa = PPAA \cdot VVBB \cdot PPDD\ CC \cdot hDD \cdot EECC \qquad (3)$$

Porosity frequently changes from being surface- or linked-linked to being closed at this fractional density. Each layer's cross-interior section can optionally have the powder laser sinter to an intermediate density that typically exceeds 80% of the theoretical density [34-36]. Material that has undergone hybrid fabrication (SLS processing and hot isostatic pressing) post-processing has a strong correlation between its microstructure and mechanical properties and that of material that has undergone traditional processing [37-39]. It is challenging to fully process M2 high speed steel particles utilized in SLS (Table 4) [40].

Table 3. Technical specifications for laser sintering machine [33].

Technical parameters	Specifications
Standard lead time	1. Depending upon the size of the component. Bigger size components take minimum of 4 working days. 2. 2. For pieces with dimensions less than 300 X 100 X 100 mm, a minimum of two working days.
Layer thickness	0.15 mm
Standard accuracy	0.3%
Minimum wall thickness	Living hinges may be made at 0.3 mm, but not at 1 mm.
Maximum construct size	1. Dimensions are limitless since components can be made up of several smaller sections. 2. 2. The size of the largest machine, which is 550 X 300 X 520 mm.
Surface architecture	1. Laser sintered parts can be sandblasted, colored/impregnated, painted, covered and coated. 2. Parts that are not finished often have a rough, granular surface; however exquisite finishes of any sort are achievable.

Table 4. Lists the SLS process parameters, separated down into categories such as material, laser, scan, and environmental characteristics [40].

Process parameters	Effects
Laser power	1. High laser powers may cause thermal stresses in the components. 2. High laser powers lasers are suitable for high melting point materials. 3. High laser power will decrease the time of sintering and increase the depth of penetration of the heat. 4. Preheated powder beds can minimize the consumption of high laser power.
Laser spot diameter	1. Intensity of the laser is high when laser beam diameter is very less. 2. Larger spot diameter more area but the intensity of the beam will be less. 3. Smaller diameter laser beams are used are used for smaller features sizes.
Layer spacing	1. Smaller gaps will lead to densely sintered powder which causes rough surface finish. 2. Larger gaps will not connect the previously sintered layer.
Atmosphere	1. Oxidant environment is not good for the reactive metals. 2. Inert atmosphere is used for reactive metals.
Laser scan speed	1. Faster scan speeds help in scanning the layer quickly but the amount of heat generated will be less. 2. Slow scan speeds will sinter excess powder and result in poor surface finish.
Part bed temperature	1. Preheated part bed will minimize the power consumption. 2. The temperature shouldn't rise over the point at which the building material will melt.
Powder characteristics	1. Absorb laser energy very efficiently. Oxygen involved powders lead to porosity. 2. Fine powder particles give good surface finish and finer powder. 3. Spherical powders also lead to porosity. Irregular and fine powders show good bonding characteristics.
Laser energy density	1. The energy absorbed by the material per unit area. 2. It depends upon laser powder, scan spacing and scan speed.
Layer thickness	1. Thin layers will give us good surface finish and these layers are used wherever the part is intricate. 2. Thicker layers need more laser energy. 3. Thicker layers lead to poor surface finish.

RECENT AND ADVANCED APPLICATIONS OF SLS PROCESS

A brief overview of the applications of SLS and DMLS methods in various sectors was provided in the section before this one [41]. After reading the next part, we will have a better understanding of how DMLS products are utilized and the materials that were used to manufacture them. Particularly, the consumer goods, automotive, aerospace, athletic footwear equipment, and motor sport industries have shown interest in the SLS and DMLS [42-45]. SLS is used in the field of bioengineering to create bone models, medication delivery systems, and scaffolds for tissue engineering [46,47]. SLS may be used to construct intricate human anatomy models utilizing information from MRI and CT images [47,48] SLS created models are used in neuro-networks for neurosurgeons to practice on since it has been demonstrated that they have higher dimensional accuracy than models created using other 3D printing techniques, such as the Poly Jet method [49, 50]. SLS permits the development of devices like ankle-foot orthoses that aid people with impaired lower limb function in enhancing their mobility capabilities [51]. Customized devices including hearing aids, dental retainers, and prosthetic limbs are frequently 3D printed using the SLS technique. Orthopedic and dental load-bearing equipment is frequently made using alloys based on titanium [52]. Due to the SLS process's fast creation of wax patterns, investment casting enables the rapid prototyping of parts that would often need months to produce [53]. Wax patterns are used in the transportation sector to swiftly create working metal prototypes of the engine or drive train. It would take a lot of time to prototype these pieces using traditional techniques [53,54].

CONCLUSIONS

Using the SLS technique to produce intricate prototype components can reduce the amount of time and money spent on the materials the system requires in the plastic and metals industries. Utilizing a variety of materials and having the option to enhance the quantity of materials that will work in the process are two advantages of employing the system. DMLS appears to be at a crossroads between limited applicability in prototype applications and greatly increased potential in the fields of component manufacturing and series production tooling. A study found that powder with a narrower size distribution melt more easily and yields materials with greater densities, superior mechanical strengths, and increased productivity. However, manufacturing virtually net-shaped things with exact tolerances and a high-quality surface polish with laser sintering does not work well. The existence of minute structural flaws in the finished product (such as voids, contaminants, or inclusions) is another problem these technologies encounter. Post processing techniques must be used to treat the portion of the sintering process that cannot be kept at full density. This indicates that more work must be done to achieve significant success in particular application areas. Future casting processes will be replaced by the direct application of additional layers of functional metallic components, such as copper alloys, titanium alloys, tool steel, fire-resistant steel, and aluminum alloys.

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