Materials Used in Solid Freeform Fabrication (SFF)

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Abstract:–This report is a review of materials used in additive manufacturing technique otherwise known as Solid Freeform Fabrication (SFF), this approach has resided largely in the prototyping realm, where the methods of producing complex freeform solid objects directly from a computer model without part- specific tooling or knowledge started. But these technologies are evolving steadily and are beginning now to encompass related systems of material addition, assembly, and insertion of components made by other processes. Furthermore, these various additive processes are starting to evolve into rapid manufacturing techniques for mass-customized products, away from narrowly defined rapid prototyping. Specific examples include: laser sintering of powders, direct metal deposition(See Fig 1) and laser fusion of powders, and ink jet printing techniques. Truly integrated layer- by-layer additive processes under development are limited. Materials requirements for SFF include the ability to produce the feedstock in a form amenable to the specific SFF process, suitable processing of the material by SFF, capability to be acceptably post- processed to enhance geometry and properties, and manifestation of necessary performance characteristics in service. As SFF has matured, septic classes of material have become associated with septic SFF processes and applications.

Keywords:- Prototyping, Free Form Fabrication, Materials.

I. INTRODUCTION

Development of new materials for use in additive manufacturing is being pursued continuously. Many of the materials that were used commonly prior to the 1996 WTEC study on rapid prototyping have been improved or replaced by alternatives that offer enhanced performance. Use of the ideal material will result in final geometries that have high definition and surface finish; have excellent mechanical, electrical, electromagnetic, chemical, or thermal properties that meet or exceed those of conventionally processed materials; are cost effective; and are environmentally benign.

Advances in the development of structural materials continues at a steady pace; this aspect of additive manufacturing is more mature than evolving areas such as additive fabrication of devices that are composed of or include biological matter.

II. LITERATURE SURVEY

A relatively large number of reviews of no biological materials used in additive manufacturing have been published since the 1996 WTEC rapid prototyping report; several of these reviews are listed in Table 1.1 and are also included in the References list. The reviews in Table 1.1 are broadly categorized in terms of the type of material of primary interest (polymer, metal, ceramic, other) and the particular manufacturing method (stereo lithography, selective laser sintering, fused deposition modeling, ink-jet or 3D printing, or other). In general, these materials reviews

- Focus on specific materials that are relevant to a variety of additive manufacturing methods, corresponding to columns in Table 1.1
- Deal primarily with specific manufacturing methods, along with an overview of various materials used in conjunction with these methods, corresponding to rows in Table 1.1.
- Provide in-depth expositions of specific manufacturing methods using specific types of materials, corresponding to single entries in Table 1.1, and/or present overviews of the physical behavior of various types of materials that may be relevant to an array of manufacturing methods, including additive.

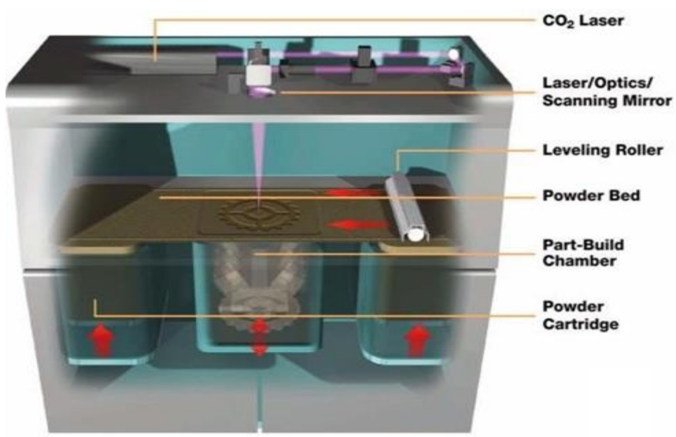

Fig. 1. 3D Printer.

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Technology	Metals	Polymers	Ceramics	Others
Stereolithogr aphy (STL)		Calvert 1998	Sigmun d 2000	
Selective Laser Sintering (SLS)	Beaman 1997	Beaman 1997	Beaman 1997	
	Das 2003	Calvert 1998	Sigmun d 2000	
	Kumar 2003	Kumar 2003		
Fused Deposition Modeling (FDM)		Calvert 1998	Sigmun d 2000	
Ink-Jet or 3D Printing	Calvert 2001	Calvert 2001	Calvert 2001	Calvert 2001
			Heule 2003	
			Sigmun d 2000	
Other	Poulikak os 1996	Calvert 2001	Beaman 1997	Sachs 201
	Armster 2002		Calvert 2001	Hague 2001
	Magee 1998		Heule 2003	
	Duty 2001		Tari 2003	
			Poulika kos 1996	
			Armster 2002	
			Duty 2001	
			Sigmun d 2000	

Table No.1. Materials and Materials Processing for Additive Manufacturing, Review Articles, 1996-2003.

III. MATERIALS USED IN SFF

For any manufacturing process, including SFF technologies, the feedstock must be formed into a state compatible with the process in question (e.g., powder, sheet, wire, liquid). For example, in vat polymerization and photopolymer-based material jetting, the feedstock must be a liquid thermoses plastic monomer that will crosslink when exposed to the appropriate electromagnetic radiation.

Finally, the material must exhibit acceptable service properties to perform successfully in the given application. For the most stringent service applications, SFF parts are usually post-processed in some fashion to improve the microstructure, reduce porosity and to finish surfaces, reduce roughness and meet geometric tolerance.

The plastics are listed as amorphous polymers, semi crystalline polymers and thermo- sets. Material extrusion uses amorphous polymers. The large viscous softening temperature range is helpful for successfully depositing the bead of plastic. Semi crystalline polymers typically soften over a very small temperature range with a dramatic change in viscosity. While this behavior is useful for powder bed fusion of plastics, the polymer flow characteristics are difficult to control using material extrusion. Chocolate is a special case and may be considered to be semi crystalline. There are several chocolate printers based on material extrusion, but the

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present quality of multiple-layer parts is generally low, often limiting these fabricators to single layer deposition. Vat polymerization is limited to photosensitive thermoses.

A. Plastics

a). Thermoplastics

Material extrusion and powder bed fusion and processes use thermoplastic polymers. Both involve thermal layer adhesion but exploit different mechanisms. For material extrusion, amorphous thermoplastics perform most suitably, while semi crystalline polymers are typically used for powder bed fusion.

b). Thermoplastics for Material Extrusion.

For the material extrusion process, amorphous thermoplastics are preferred, due to their melt characteristics. These polymers, including popular ABS and PLA, soften over a wide range of temperature up to the so- called glazing temperature, forming a high-viscosity material ideal for material extrusion through a 0.2–0.5 mm diameter nozzle. Table 1.2 lists commercially available materials for material extrusion.

Technology	**Metals**	**Polymers**	**Ceramics**	**Others**
Stereolithogr aphy (STL)		Calvert 1998	Sigmun d 2000	
Selective Laser Sintering (SLS)	Beaman 1997	Beaman 1997	Beaman 1997	
	Das 2003	Calvert 1998	Sigmun d 2000	
	Kumar 2003	Kumar 2003		
Fused Deposition Modeling (FDM)		Calvert 1998	Sigmun d 2000	
Ink-Jet or 3D Printing	Calvert 2001	Calvert 2001	Calvert 2001	Calvert 2001
			Heule 2003	
			Sigmun d 2000	
Other	Poulikak os 1996	Calvert 2001	Beaman 1997	Sachs 201
	Armster 2002		Calvert 2001	Hague 2001
	Magee 1998		Heule 2003	
	Duty 2001		Tari 2003	
			Poulika kos 1996	
			Armster 2002	
			Duty 2001	
			Sigmun d 2000	

Table No.2. Current Commercial Materials Directly Processed By AM, By AM Process Category.

B. Thermo Sets

Typical photopolymer materials used in SFF are composed of monomers, oligomers, photo initiators, and a variety of other additives including inhibitors, dyes, antifoaming agents, antioxidants, toughening agents, etc. that help fine-tune the photo- polymer's behaviors and properties. The first photopolymers used in vat photo polymerization were mixtures of UV photo- initiators and acrylate monomers. Vinyl ethers were another class of monomers that were used in early resins. Acryl ate and vinyl ether resins exhibited considerable shrinkage, from 5 to 20%, which caused residual stresses to accumulate as parts were built layer-by-layer which, in turn, caused significant war page. Another disadvantage of acryl ate resins is that their polymerize- tion reactions are inhibited by atmospheric oxygen. To overcome many of these disadvantages, epoxies were introduced in the early 1990's and brought significant advantages to the vat photoplay- mediation process, but complicated the formulation of resins.

C. Metals

Powder bed fusion and directed energy deposition are the main powder-based SFF processes that are commercially used to manufacture quality metal parts. A metal wire feed can also be used instead of powder feed in DED. Binder jetting is also used to produce metal parts. Polymer matrix parts are made that need furnace de-binding and sintering and/or infiltration with a lower melting point metal (e.g., brass) to obtain dense metal parts.

The set of common commercially available alloys is limited to pure titanium, Ti6Al4V, 316L stainless steel, 17-4PH stainless steel and 18Ni300 managing steel, AlSi10Mg, CoCrMo, and nickel based super alloys Inconel 718 and Inconel 625. This range is continually expanding with new entrants to the materials supply market. Precious metals such as gold, silver or platinum have been processed indirectly by 3D printing of lost wax models, but are currently also being directly used in selective laser melting. Several factors contribute to this limited metal palette. When fusion is involved, the metals generally must be wieldable and cast able to be successfully processed in SFF. The small, moving melt pool is significantly smaller than the dimensions of the final part (typically on the order of 10^2–10^4 times smaller). This local hot zone in direct contact with a large and colder area leads to large thermal gradients causing significant thermal residual stresses and non-equilibrium micro structures.

D. Ceramics

Several reviews of SFF of ceramics have been published. Ceramics, due to their combination of high melting point and low toughness, are difficult to process directly in SFF. Alumina and its alloys have been directly processed using directed energy deposition and powder bed fusion, but full density processing is difficult. In most cases, attempts to direct process ceramics have resulted in thermally induced cracking. Approaches to mitigate cracking include process optimization, adding auxiliary devices (ultrasonic, thermal, magnetic) and a doping toughening approach. Process optimization for directed energy deposition of crack- free alumina includes high scan speed exceeding 700 mm/min.

Indirect SFF processing of ceramics requires use of a binder in some form that holds the part together after SFF. With the exception of directed energy deposition, all categories of SFF have been utilized in creation of indirect SFF ceramic part. In the mid- 1990s sheet lamination methods were used for processing alumina/zircon, silicon carbide and silicon nitride

E. Composites

Composite development takes into consideration the following factors: feedstock material and preparation (molten, lament, brows, particulate), homogeneity and properties. It is vital that the interface between the matrix and the dispersed or embedded phase be engineered for proper bonding, transfer of load and protection against corrosion. Under consideration here are composites fabricated by additive manufacturing without post-processing such as in alteration or coating.

F. Polymer composites

Material extrusion processes allow for discrete, heterogeneous layering of a material for a laminate composite. The feedstock may alternatively be formulated prior to deposition for a matrix composite. Additives to polymer feedstock must be of the proper composition to yield an extradite that is of low enough viscosity to deposit and provide strength over the entire part build time. Feedstock often consists of the matrix polymer, tackier, plasticizer, surfactant, and secondary phases such as particulates or beers of metal, ceramic or polymer composition. Tackier provide edibility, plasticizers improve theology, and surfactants change dispersion character of the secondary phase. Polymer composites with dispersed annotates have been achieved by formulating operational feedstock

G. Metal Composites

Metal-matrix composites fabricated using SFF include portico- late composites, fibrous composites, laminates and functionally gradient materials (FGMs). SLM and laser metal deposition (LMD) are highly favored processes for SFF of

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metallic materials.

It is possible to fabricate metallic composites from powder precursors by liquid phase sintering (LPS) to bind the matrix material and secondary phases. This technique has been applied to metal-matrix composites (MMCs) for full consolidation and improved sinter ability. In the case of WC-Co/Cu composites, with WC particulates reinforcing the Co matrix, bronze (Cu–Sn) or copper additive is used for LPS; other additives such as lanthanum oxide can be used to decrease surface tension to improve desiccation.

H. Ceramic Matrix Composites

Biomaterials is a major area driving SFF research and development in SFF of ceramics. Select biomaterial scaffolds of ceramic in polymer require no sintering or post treatment and are effectively available for use immediately after fabrication. Much like the biopolymer composites, the bioceramic composites are particulates blended for homogeneity and then consolidated via selective laser sintering (SLS) or some other SFF process.

IV. CONCLUSION

Today, RP technologies have been on the market for almost three decades. They still enjoy growing interest in industry and science. This increasing recognition is rejected in a cumulative number of technological developments in the field of LM and a steadily increasing number of sold RP units.

Recent advancements made in other fields of materials science have stimulated progress of RP materials development. Composites and in particular nano composites, though well established in other fields of materials science, have entered RP technologies only in recent years, resulting in materials with substantially improved mechanical and thermal properties, and processes with increased dimensional accuracy. Owing to the accomplished progress, LM's scope of application widens steadily from concept modeling to functional prototyping, RT and manufacturing.

Beyond the described advancements, a growing interest in development of novel materials and processes for medical applications is noticed. Up to now, freeform fabrication of patient-septic osteoconductive implants for bone regret represents the most investigated of such applications. However, it appears likely that research RP developments will address further tasks in tissue engineering and organ printing in the near future.

Despite the described sciatic progress and further, often numerical investigations aiming at a better understanding of LM processes, the appropriate choice of an RP process for a given application is still dependent on precise knowledge of individual strengths and weaknesses of the various technologies offered on the market. Especially concerning applications exceeding mere design visualization, decisions based on accurate knowledge of processes and materials are required to enable LM to compete with formative and subtractive fabrication techniques. The overview given in this article is meant to support both users and researchers in taking the right choices.

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