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Additive Manufacturing Process: Materials Status and Opportunity

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ABSTRACT
Additive manufacturing (AM) techniques provide a technological tool for making solid free form products. AM technique uses a wide range of materials developed by various groups of technology and has become an alternative to conventional manufacturing techniques to produce better quality product at less cost, shorter lead times and with more customer delights. To make this technology viable development of a database of material properties, test center to test material properties and more investigation to improve fabricated parts properties, its accuracy and development of new materials for various applications is required. Currently, limited materials are available with a very high cost that impedes growing number of applications of AM process. Apart from these many technical challenges, including process control and modelling would benefit in producing high strength parts with good aesthetic quality satisfying the customer needs. Additionally, interest in multifunctional structures and multiple materials automatically poses a task for today's additive manufacturing (AM) technologies; however, the ability to process multiple materials is a fundamental advantage to some AM technologies. The capability to fabricate multiple material parts can improve AM technologies by either optimizing the mechanical properties of the parts or providing additional functions to the final parts.

Keywords: additive manufacturing, composite materials, hybrid materials, multiple materials additive manufacturing, selective laser sintering

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INTRODUCTION

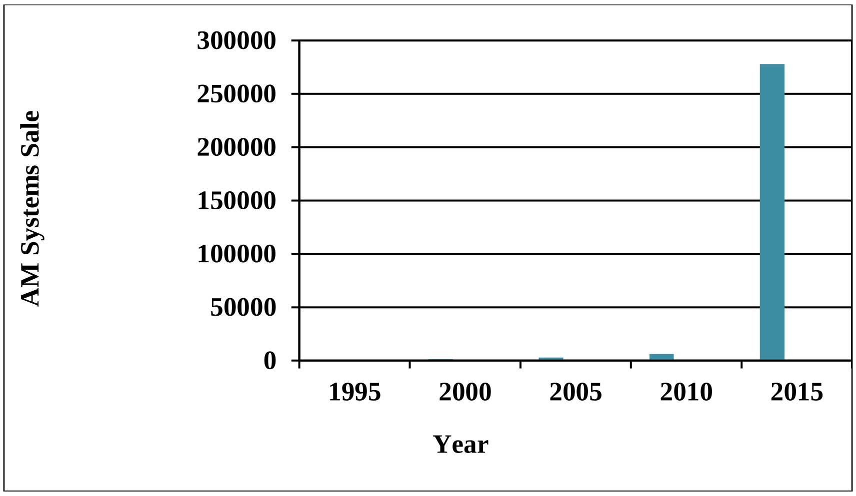
Additive manufacturing (AM) is a new group of automated manufacturing which allows fabrication of physical models of any complexity using layer-by-layer deposition technique directly from computer aided design (CAD) model by selective fusion, sintering or polymerization of material which may range from wax, cermets, polymer, metal, ceramic and biomaterials [1]. It is also energy saving, highly productive and sustainable manufacturing processes [2, 3]. AM process greatly reduces the time and cost necessary to bring a new product to the market with the freedom to produce any kind of geometry without using any special tool, as required in the case of conventional manufacturing [4, 5]. The AM technique concept was introduced in the late 1980s. AM techniques have been made commercially available in the market during last 24 years.

The first AM technique, SLA by 3D systems in the year 1988 has become the pioneer in the AM market. Initially, AM system was bigger in size, more costly and the parts made from them were limited to specific applications only. At present, there are over 50 vendors around the world marketing a large range of AM systems, with each system having its own strengths, limitations and applications [6]. Other than SLA currently several AM technologies exist, classified as, Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Fused Deposition Modeling (FDM), Laminated Object Manufacturing (LOM), 3DPrinting (3DP), etc. where Wong and Aldo (2010) reported four new technologies namely, Electron Beam Melting (EBM), ProMetal, Laminated Engineered Net Shaping (LENS) and Polyjet which is added in year after 2004 [7–9]. AM systems differ mainly based on materials they use to build the part, for e.g. powder, filament, and liquid raw state. Secondly, based on the process to create model e.g. SLS, SLA, FDM, LOM, LENS, etc.

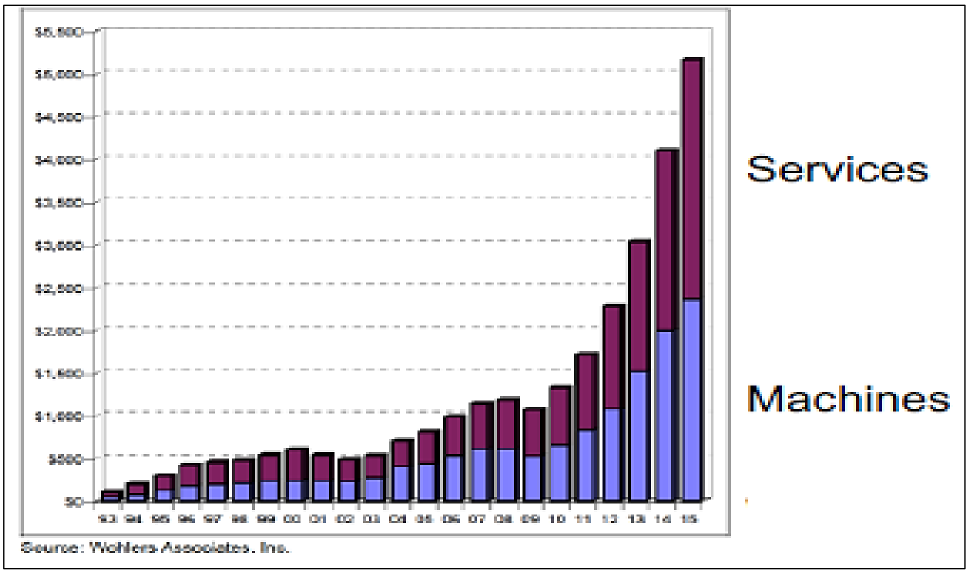
AM systems classified on the basis of raw materials used for manufacturing is as Liquid based: Stereolithography (SLA), Polyjet technology, Solid Curing System (SCS), Digital Light Processing (DLP), E-Darts, Solid Object Ultraviolet, 3D Bioplotter and Acculas technology, Solid based: Fused deposition modelling (FDM), Shape Deposition Manufacturing, Benchtop System, Laminated Object Manufacturing (LOM), and CAM-LEM technology and Powder based: Selective Laser Sintering (SLS), 3D Printing (3DP), Electron Beam Melting (EBM), Laser Engineering Net Shaping (LENS), Selective Mask Sintering (SMS) and Voxjet system [6–10].

These AM techniques have capabilities to produce any kind of geometry easily, cost effectively and efficiently as compared to conventional manufacturing [1]. This makes AM acceptable in various field of manufacturing. Wohler’s (2016) reported in their annual worldwide progress report on additive manufacturing and 3D printing state of the industry that the total annual revenue for the AM industry for the year 2015 has been well over $5.2 billion and reported 26% growth for the year 2015 and also 26% Cumulative Growth Annual Rate (CGAR) for 27 years [11].

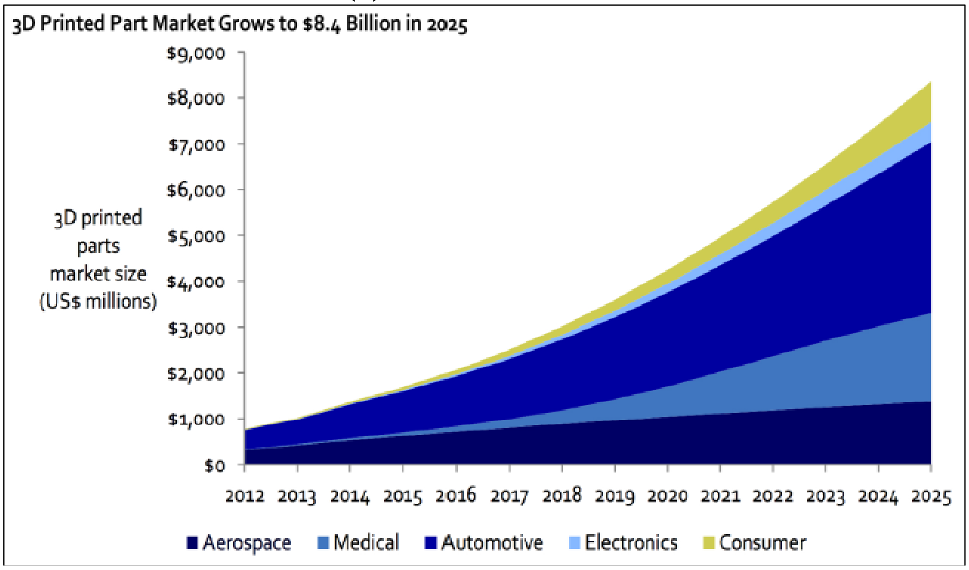
The system sale for AM was approximate 2800 unit machines in the year 2005, above 6000 unit machines in the year 2010 and 278000 unit machines in the year 2015. Figure 1 shows the AM system sales worldwide [11].



(a) AM systems sales worldwide

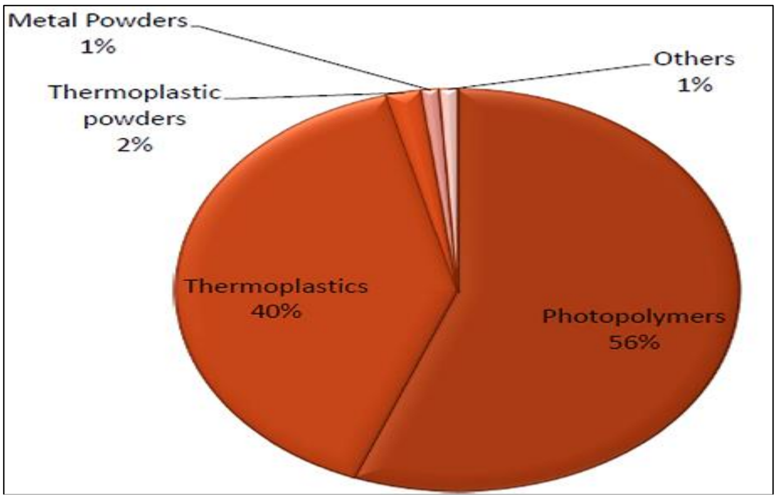


(b) AM market status

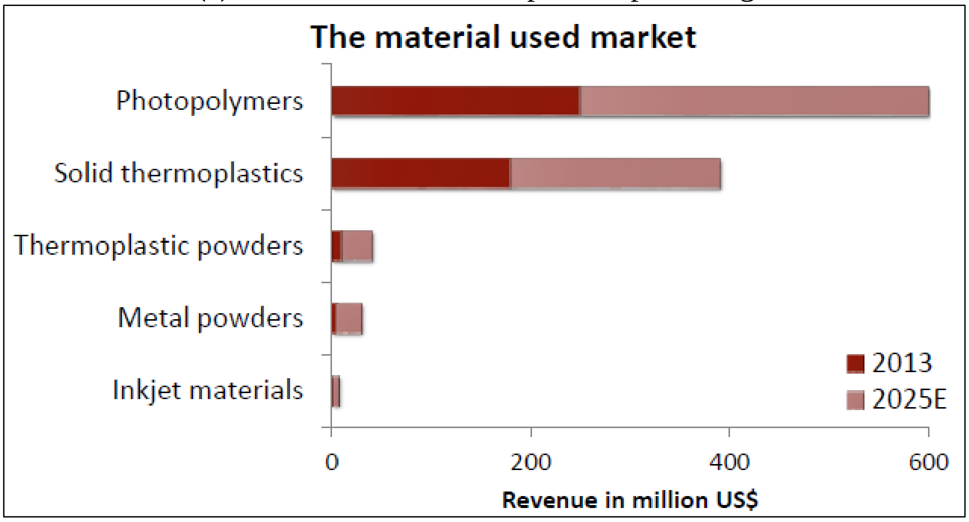


(c) Additive manufacturing market

Fig. 1. *(a–c) AM growth trend and market status [11, 12].*



(a) Material used for AM process percentage



(b) Material used market

Fig. 2. *(a, b) Additive manufacturing material status [13].*

Figure 2 shows the data of AM materials in the market for different applications in which photopolymer and thermoplastics are currently mostly used material which contributes major revenue for AM process [13].

Figure 3 shows the approximate AM percentage uses in the Asia/Pacific region by the end of the year 2016. The use of AM for direct part production worldwide is shown in Figure 4 [11]. Figure 5 shows the percentage of response for different AM processes [11, 12]. From Figures 3 and 4 it has been depicted that AM process is mostly used in Japan and China and Japan and percentage use for direct part fabrication is increasing continuously. Figure 5 shows that SLS process is mostly used for various applications in comparison to all available processes.

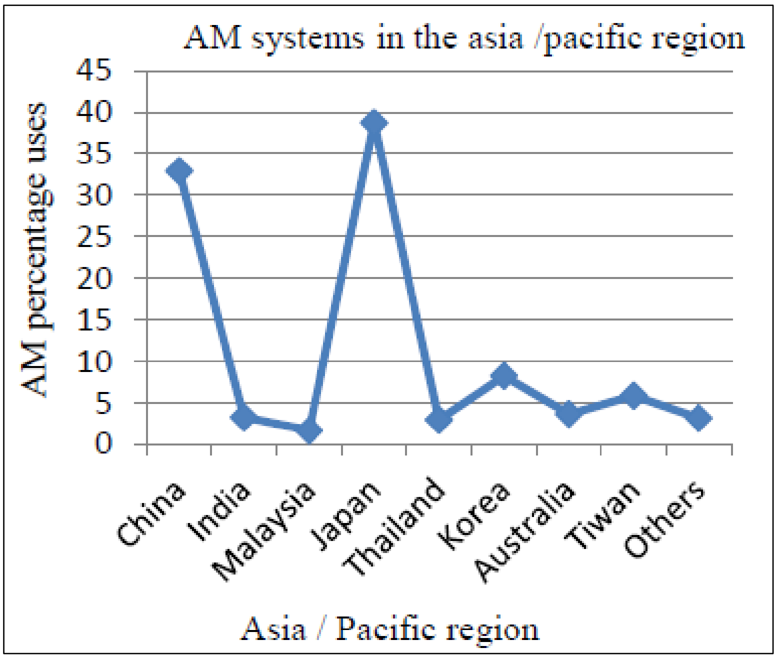


Fig. 3. *Approximate AM percentage uses in the Asia/Pacific region by the end of the year 2016 [12].*

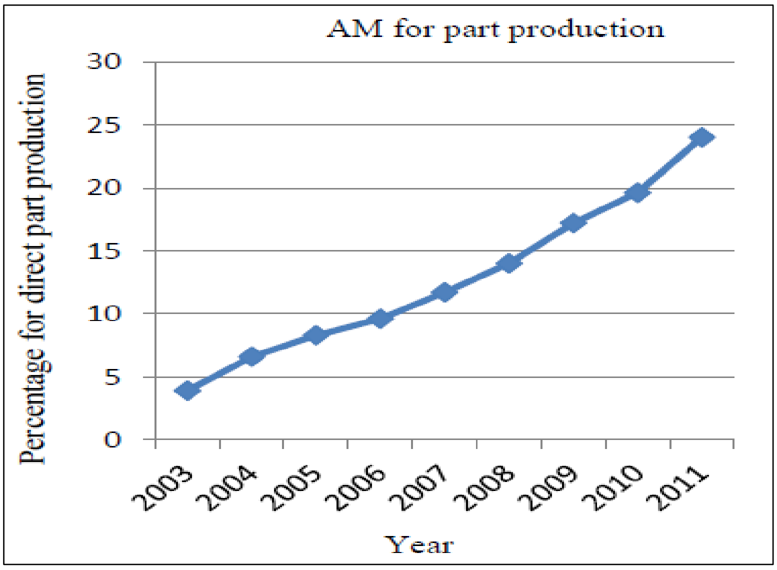


Fig. 4. *Use of AM for direct part production worldwide [11].*

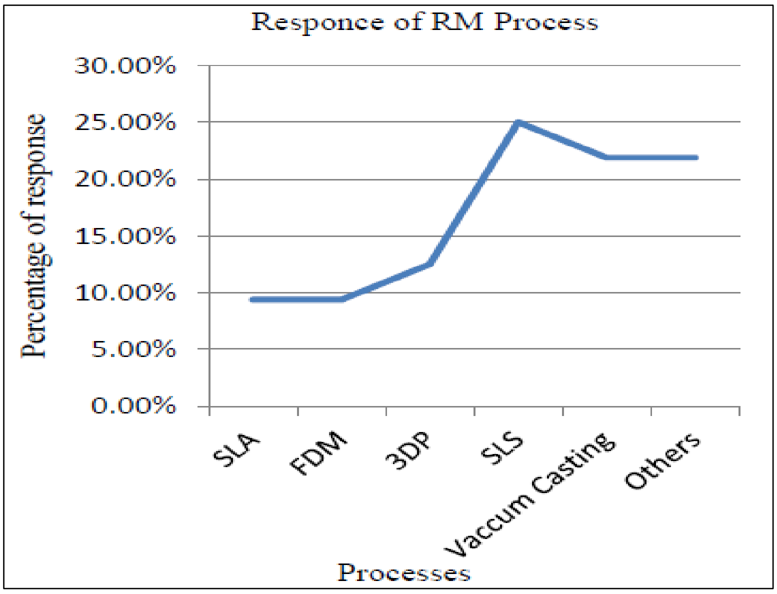


Fig. 5. *Percentage of response for different AM processes [11, 12].*

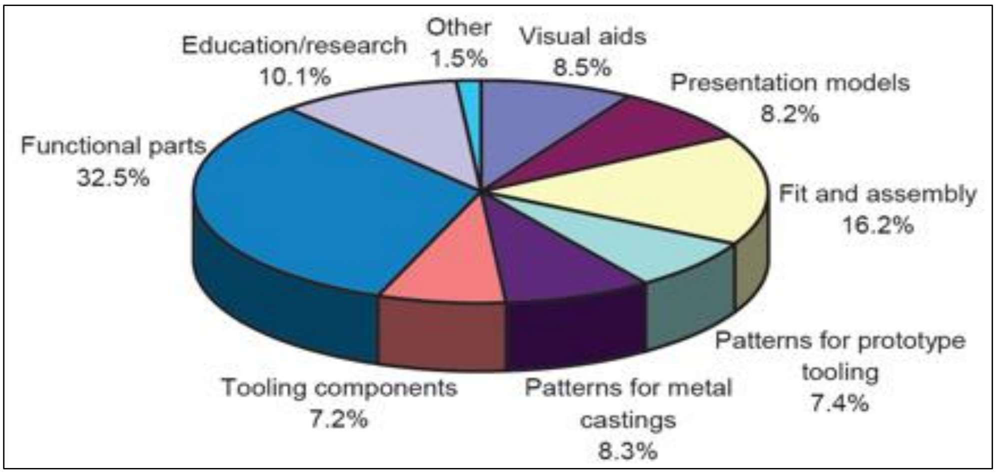


Fig. 6. *Percentage uses of AM in different applications [12].*

The AM market status for different application is shown in Figure 6 [12]. The AM systems have been mostly used in manufacturing industries such as automobile, medical field, aerospace industry electric home appliance and jewelers industry [14].

AM Materials

SLS Materials

Since SLS process emergence it has found applications in various industries with the use of various materials. Across all industries, worldwide sales of materials, equipment and services for additive manufacturing process accounted about $5.2 billion up to the year 2015 [12]. SLS process materials are wax, cermets, ceramic (e.g., Al_2O_3, FeO, NiO, ZrO_2, SiO_2 and CuO), polymers (e.g., PVC, PE, PP, PMMA, PS, PET, PA and PC), metals (e.g., Al, Cr, Ti, Fe, Cu), metals system (e.g., Fe-Cu, Fe-Sn, Cu-Sn) and alloys (e.g., cobalt-based, nickel based, bronze-nickel, pre-alloyed bronze-nickel, Inconel 625, Ti- 6Al-4V, stainless steel, gas-atomized stainless steel 316L, AISI 1018 carbon steel, high-speed steel pre-coated foundry sand and alumina with polymer binder), bio-material and combinations of (metals and polymers), (metals and ceramics), etc. [8, 15–43]. Apart from this SLS material developed by various groups of technology as 3D Systems, CRP Technology, EOS Technology, MTT Technologies including and Advanced Laser Materials (ALM) are also reported which makes this technology viable and alternative to the conventional manufacturing.

3D Systems manufacturer of SLS materials has developed various materials like DuraForm PA, DuraForm GF, DuraForm AF polyamide aluminium powder, DuraForm Flex, DuraForm EX, DuraForm PP 100, DuraForm HST, Cactiform PS polystyrene powder, LaserForm™ A6 polymer-coated A6 steel and tungsten-carbide powders.

CRP Technology is a manufacturer of SLS materials like Windform GF (Aluminium and glass filled nylon powder), Windform PRO B, Windform XT carbon and nylon composite powder and Windform LX 2.0 polyamide based material. EOS Technology manufactures SLS materials like, PrimePart®, EOSPEEK, EOSPEEK HP3 a thermoplastic polyaryletherketone (PAEK) group powder, PA2210 FR a polyamide powder, PA 2201, PA 2202 black, Carbonamides a carbon fiber-filled polyamide powder, PA 2200, PA 3200 GF a glass-filled polyamide powder, PrimeCast® 101 a polystyrene powder, Prime Part® DC, Alumide, a 30% aluminium filled polyamide, DirectMetal 20 a fine-grained bronze-based metal powder, StainlessSteel GP1 is a fine-grained pre-alloyed stainless steel powder alloying elements as Cr, Ni, Cu, Mn, Si, Mo, Nb, C, etc., EOS StainlessSteel PH1 a fine-grained stainless steel powder including alloy elements as with different composition of above alloying elements of GP1, MaragingSteel MS1 a pre-alloyed, ultra-high strength steel powder containing Fe, Ni, Co, Mo, Ti, Al, Cr, C, Mn, Si, P, S, EOS CobaltChrome MP1 a fine-grained CoCrMo based super alloy powder contains Co, Cr, Mo, Si, Mn, Fe, C, EOS CobaltChrome SP2 a fine-grained Co, Cr, Mo, and W (cobalt chrome- molybdenum) based alloy powder which contains Co, Cr, Mo, W, Si, Fe, Mn and composition corresponds for type 4 CoCr dental material standard, EOS Titanium a fine-grained pre-alloyed Ti-Al6-V4 alloy powder EOS Nickel Alloy IN718 a nickel alloy powder and EOS Aluminium.

MTT Technologies manufacture several SLS materials like Titanium, Alulminium based alloys, etc. Titanium based materials include cp-titanium, Ti Al6Nb7, Ti Al6 V4. Aluminium based materials include AlSi12 and AlSi10 Mg aluminium alloy powder. CoCr ASTM F75and materials such as (1.4404 (316L), 1.2344 (H13), 1.4410, 1.2709, 1.4542 (17-4PH) and M333) are either tool steel or stainless steel materials [10–12, 14, 44]. ALM laser sintering unfilled nylon 11 materials, PA 850, PA 860, PA D80-ST a color stabilized material. Filled Nylon 11 materials, PA 802-CF, PA 803-CF, PA 815 –GS is off-white, 50% glass sphere filled nylon 11 powders, PA 820-MF a mineral fiber filled nylon 11, PA 840-GSL a lightweight composite material with a density of 0.86. ALM Unfilled Nylon 12, PA 250, PA 650. Filled Nylon 12 materials like PA 415-GS glass sphere filled nylon 12, PA 550-ACF aluminium and carbon fiber filled nylon 12, PA 601-CF carbon fiber filled nylon 12, PA 603-CF is high loaded with carbon fiber, PA 605-50% aluminium filled nylon 12, PA 614-GS, PA 615-GS a highly glass filled powder, PA 625-MF a mineral fiber filled nylon 12, PA 640-GSL a glass sphere filled nylon12, PA 250-ACF an aluminum and carbon fiber filled nylon 12 graphite color powder. Fire retardant performance sintering materials like FR 106 nylon 11 material, PA 606 FR is a fire retardant nylon 12 that fulfils 12 and 60 second burn, smoke and toxicity specifications. TPE (Flex) performance sintering materials like TPE 210-S are thermoplastics. Investment casting materials such as PS 100 and PS 200 a non-spherical polystyrene powder [14, 44].

Table 1 shows the material development stage for SLS process with improvement in their characteristics in consecutive years [14].

Table 1. *Material development stage [14].*

Year	Material type	Characteristics
1992	Wax	First sintering material for SLS
1993	Nylon 11	Good final properties
1997	Nylon 12	Wider processing window
2000	Polystyrene	Advanced performance materials
2005	New grades of Nylon 11 & 12	Enhanced mechanical properties
2010	PEEK	Enhanced mechanical properties
2012	Nylon 6, PP, PEEK, Mid temperature	True manufacturing

SLS Materials Properties

Nowadays several materials are available in the market developed by various technologies and researchers which have distinct properties. These materials are categories as Polymer, Metals, Ceramic, Composite and Bio- materials. The understanding of materials properties from given range will help in the appropriate selection of material which may satisfy the customer requirements with cheaper in cost. Figure 7 shows SLS process materials particle size range in which average particle size is taken for Composites and Bio-material is 20 μm. Figure 8 shows SLS materials tensile strength (MPa) range.

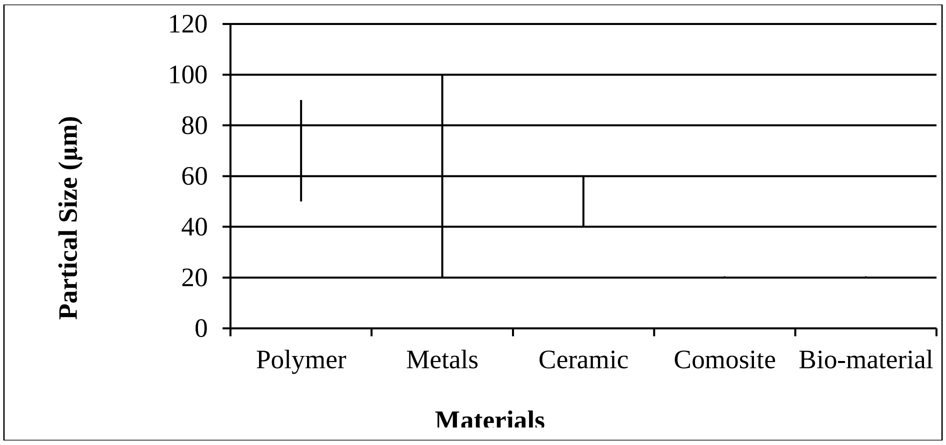


Fig. 7. *SLS process materials particle size (μm) range.*

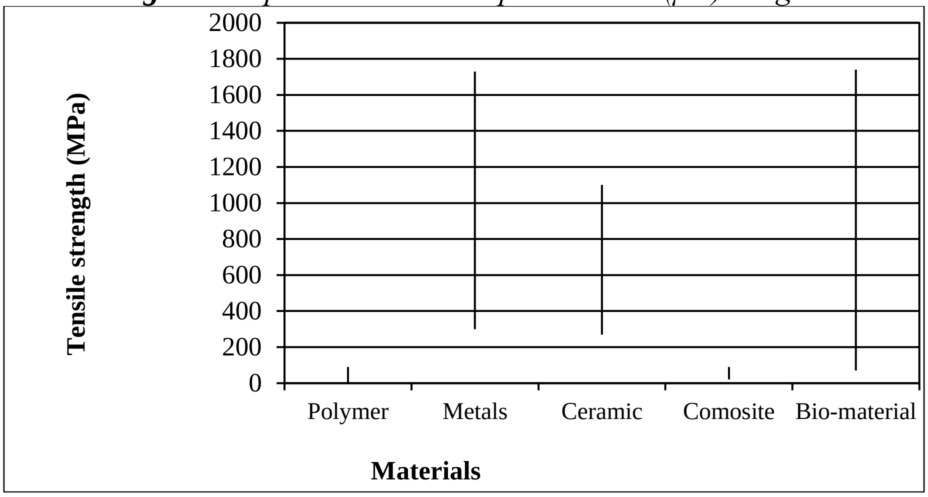


Fig. 8. *SLS materials tensile strength (MPa) range.*

Figure 9 shows SLS tensile modulus/ elastic modulus (MPa) range. Figure 10 shows SLS materials elongation % at break/yields range. Figure 11 shows SLS materials impact strength (J/m) range. Figure 12 shows SLS materials hardness (ShoreD-scale) range. Figure 113 shows SLS polymer materials glass transition temperature (ºC) range. Figure 14 shows SLS materials melting point temperature (ºĊ) range. Figure 15 shows SLS materials density (g/cm^3) range [10–12, 14, 44–47].

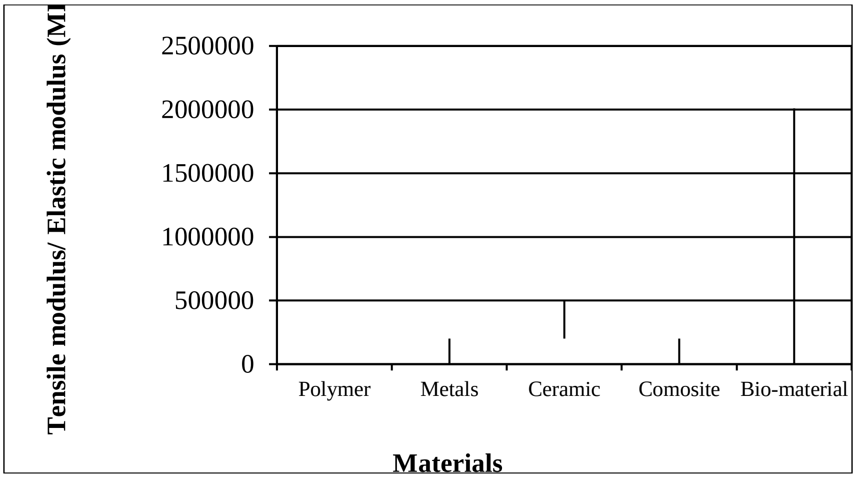


Fig. 9. *SLS tensile modulus/ elastic modulus (MPa) range.*

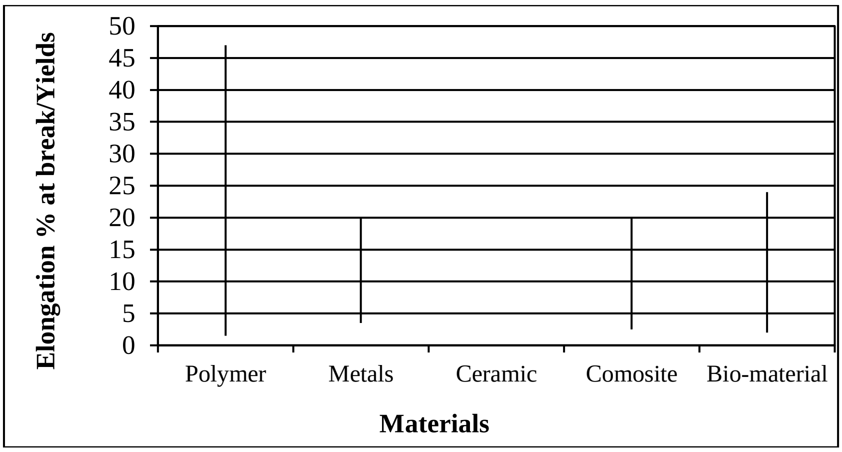


Fig. 10. *SLS materials elongation % at break/yields range.*

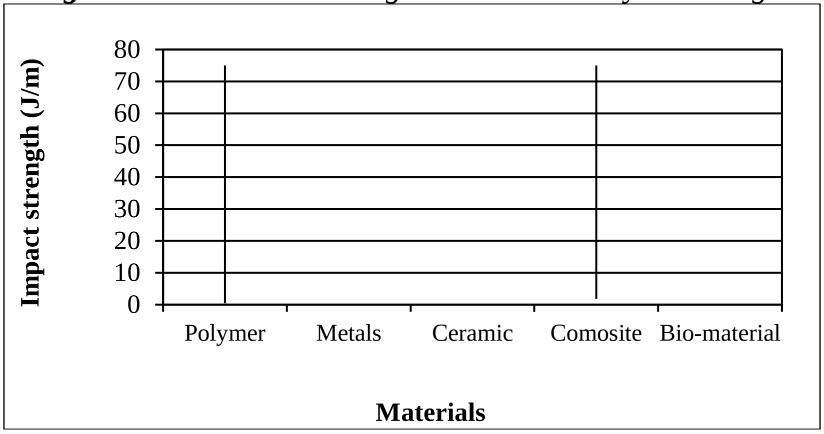


Fig. 11. *SLS materials impact strength (J/m) range.*

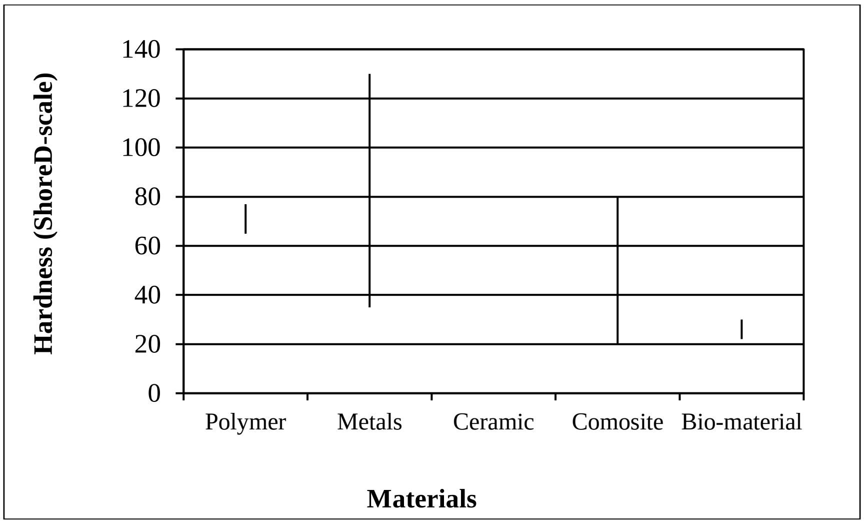


Fig. 12. *SLS materials hardness (ShoreD-scale) range.*

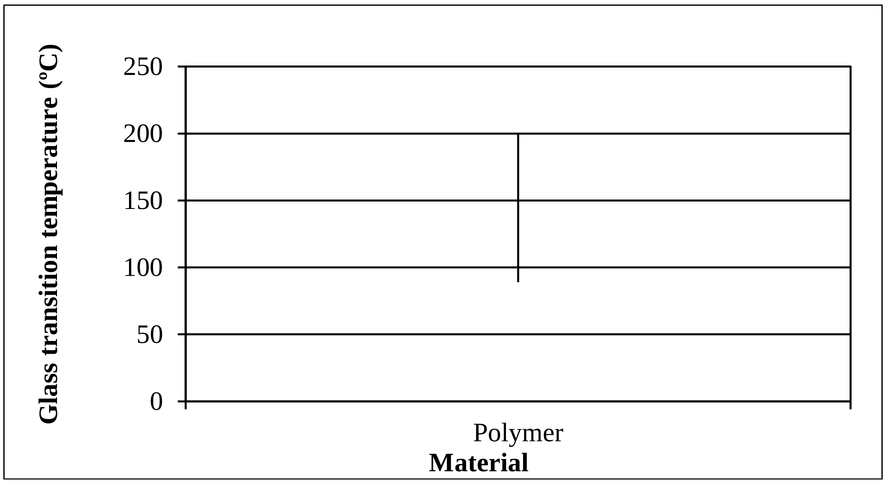


Fig. 13. *SLS polymer materials glass transition temperature (ºC) range.*

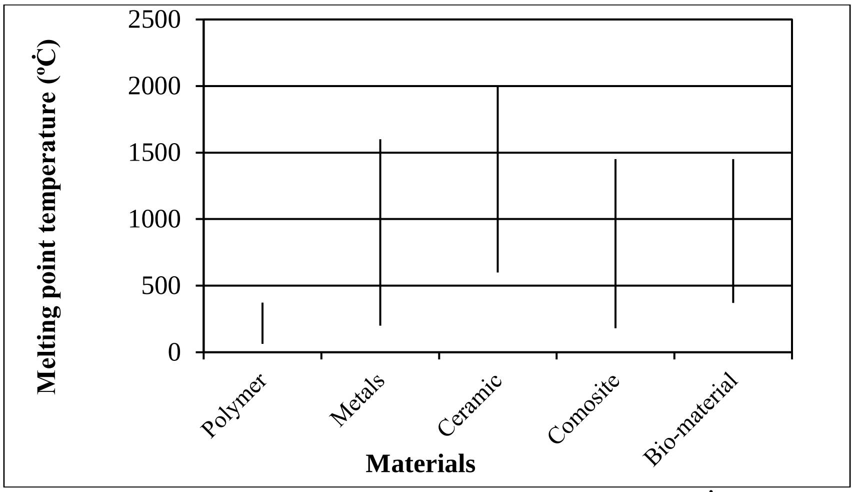


Fig. 14. *SLS materials melting point temperature (ºĊ) range.*

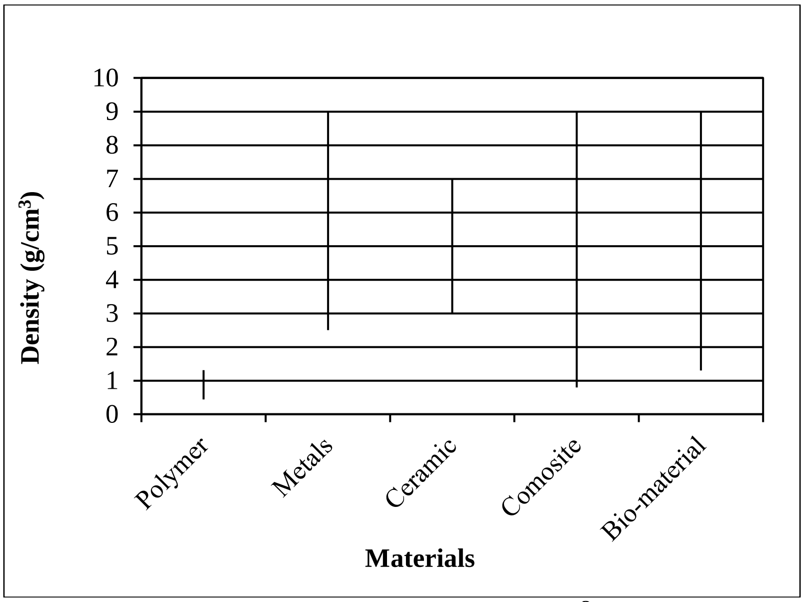


Fig. 15. *SLS materials density (g/cm^3) range.*

SLS Materials Applications

SLS process uses wide range of materials to make prototypes; functional prototypes and end use products for various fields of applications like biomedical, engineering (aerospace, automobile, architectural, etc.) and some others gives it an edge over other AM techniques. In engineering field for making part of, aerospace components with the use of materials such as PEEK, DuraForm PA, DuraForm EX impact-resistant plastic, EOS Titanium Ti64, EOS MaragingSteel MS1 and EOS Nickel Alloy IN718, automotive components with the use of materials such as Acrylonitrile butadiene styrene (ABS), polycarbonate (PC), PEEK, Alumide®, nylon 11 and 12, Al–SiC composites, EOS Titanium Ti64, PA 640-GSL is glass sphere filled nylon12, PA6, PMMA, DuraForm PA, DuraForm GF, DuraForm EX, DuraForm HST, EOS Aluminium, PA 850 black and PA 640-GSL, etc. wind tunnel with the use of materials as PA 603-CF, Aklomide® and carbonamides, Investment casting with the use of materials as Partially stabilized Zirconia (PSZ), Aluminium with SiC, PS 100, PS 200, PrimeCast® 101 and CastForm PS, Tooling with the use of materials as LaserForm ST – 100, LaserForm™ A6, H13, RapidSteel 1.0 and 2.0 and MaragingSteel MS1, Metallic molds for injection molding with the use of materials as Nylon12/ carbon black composite, Nickle-bronze powders, Alumide®, DirectMetal 20, DirectSteel H20, EOS MaragingSteel MS1, 1.4404 (316L), 1.2344 (H13), 1.4410, 1.2709, 1.4542 (17-4PH) and M333. Fire retardant components with the use of materials as FR 106 nylon 11 material, PA 606 FR nylon 12 material and PA2210 FR a polyamide powder, Functional prototype and small series production with the use of materials as LaserForm™ A6 polymer-coated A6 steel and tungsten-carbide powders, StainlessSteel GP1, EOS StainlessSteel PH1, EOS MaragingSteel MS1, DuraForm PA, DuraForm GF glass-filled polyamide powder, DuraForm HST (composite material), PrimePart, PA2210, CarbonMide, DirectSteel H20, and PA2202, Bearings, Gears and rollers fabrication with the use of materials as PA6, Prototypes with the use of materials as wax, DuraForm PP 100, DuraForm EX, DuraForm PA, DuraForm GF, DuraForm AF, PA 650 and Windfarm series powders etc. Rubber like application (e.g. gasket, hose and seals) with the use of materials as DuraForm Flex, Turbine and engine parts with the use of materials as EOS CobaltChrome MP1, EOS Titanium Ti64/Ti64ELI, EOS Nickel Alloy IN718, SiC/Ti (MMC) and partially stabilized zirconia (PSZ) and fiber reinforced ceramic, Electro discharge machining (EDM) electrode with the use of materials as Zirconium Diboride/Copper, Graphite, Copper-tungsten, Copper, Tungsten, Tungsten Carbide, Steel, Aluminum, Copper-nickel and molybdenum alloys and Zinc. In medical field it is used for fabricating the parts like, *biomedical implants and prostheses* with the use of materials as 316L Stainless Steel, Titanium based materials include cp-titanium, Ti Al6Nb7, Ti Al6 V4, CoCr ASTM F75, EOS CobaltChrome MP1, EOS Titanium Ti64, EOS PEEK HP3, UHMWPE (M.W. >2×106 g/mol) (specially for orthopedic implants), nylons, polyacetal, polysulfone, and polycarbonate and for prostheses it uses Prime part, PA / 1220 / 2201, Polypropylene (PP), PMMA (bone prostheses), sPro 140 and sPro 60 SD / HD materials, dental applications with the use of materials as EOS CobaltChrome SP2, EOS CobaltChrome SP1, EOS CobaltChrome MP1, Dental amalgam (mixture of liquid mercury and other solid metal particulate alloy formed by silver). Apart from these material some materials are reported by Wong and Bronzino (2007) in which one of the solid alloys is composed of at least 65% silver, and not more than 29% tin, 6% copper, 2% zinc, and 3% mercury) and Alumina (Al_2O_3), Zirconia (ZrO_3), Pyrolytic carbon, Bioglass ($Na_2OCaOP_2O_3$-SiO), Hydroxyapatite [Ca_{10} $(PO_4)_6$ $(OH)_2$], and Tricalcium Phosphate [$Ca_3(PO_4)_2$], ProJet 6000and ProJet MP 3000, hearing aids with the use of materials as Nylon polyamide, iPro 800 MP, tissue engineering with the use of materials as Polylactic acid polyglycolic acid, polylactide-co-glycolide, eye glass frames and lenses with the use of materials as Nylon 11and 12, PMMA (lenses). And for fabricating medical devices with the use of materials as PC (in the heart/lung assist devices), Polyesters (artificial vascular graft, sutures, and meshes), ABS (used for IV sets, clamps, blood dialyzers and diagnostic test kits), PMMA (used for blood pump and reservoir, an IV system, membranes for blood dialyzer, and for in vitro diagnostics), PP (used to make disposable hypothermic syringes, blood oxygenator membrane, packaging for devices, solutions, and drugs, suture, artificial vascular grafts, nonwoven fabrics, etc.), HDPE (used in pharmaceutical bottles, nonwoven fabrics, and caps) and PVC (PVC sheets and films are used in blood and solution storage bags and surgical packaging, PVC tubing is commonly used in intravenous (IV) administration, dialysis devices, catheters, and cannulae), etc. Apart from these applications it has also been used in several other like, kitchenware, housings, covers, and containers with the use of materials as Polyethylene low density (LDPE), Polyethylene high density (HDPE), Polycarbonate (PC), ABS, DuraForm GF glass-filled polyamide powder, PA 640-GSL, PA 3200 GF, PP and PVC and for Art, architectural, geographic information system (GIS) and hobby with the use of materials as wax, plastics, DuraForm PP 100, DuraForm EX, DuraForm PA, DuraForm GF, DuraForm AF, PA 650 and WindForm series powders, PA 250, PA 850 Black, PA 640-GSL (mineral fiber filled nylon 12) and PA-250 ACF,. [7–9, 10–12, 14, 44–47].

SLA Materials

SLA materials mostly are photopolymer liquid resin and composite filled photopolymer liquid resin. The SLA materials developed by various groups of technology are reported below.

3D Systems manufacturer of SLA materials has developed various materials like Accura Xtreme, Accura 60, Accura 10, Accura 25, Accura 55, Accura 40, Accura Bluestone, Accura 45 HC, Accura 50, Accura Amethyst, Accura® AccuGen™, Accura® 48HTR™, Accura PEAK and Accura E-Stone.

DSM Somos manufacturer of SLA materials has developed various materials like Somos ProtoGen 18120, Somos ProtoGen 18420, Somos ProtoGen 18920, Somos ProtoCast AF19122, DMX-SL 100, WaterClear Ultra 10122, Somos 7110, Somos 8110, Somos 9110, Somos WaterClear 10110, Somos WaterShed 11110, WaterShed XC 11122, Solos Prototheme 12110, Somos 7120, Somos 8120, Somos 9120, Somos WaterClear 10120, Somos WaterShed 11120, Somos ProtoTherm 12120, Somos 9920, Somos 14120 White, Somos NanoForm 15120, Somos ULM 17220 Black, Somos 9420 EP-White, Somos NanoTool, Somos NeXt.

Huntsman manufacturer of SLA materials has developed various materials like Renshape SL-5170, Renshape SL-5240, Renshape SL-5260, Renshape SL-5530, RenShape SL-7510, RenShape SL-7520, RenShape SL-7540, RenShape SL-7545, RenShape SL-7560, RenShape SL-7565, RenShape SL-7570, RenShape SL-7580, RenShape SL-7800, RenShape SL-7810, Renshape SL-5195, Renshape SL-5510, Renshape H-C 9100, RenShape Y-C 9300, RenShape Y-C 9500 and RenShape Y-C 9500 FT1.

Allied PhotoPolymers manufacturer of SLA materials has developed various materials like KZ-1850-CL, KZ-1850-ICE, KZ-1860-CL, KZ-1870-WH.

FDM Materials

FDM materials mostly are polymers. The FDM materials developed by various groups of technology are reported below.

Stratasys manufacturer of FDM materials has developed various materials like ABS, ABSi, Polycarbonate (PC), Polycarbonate ISO, Polyphenylsulfone (PPSF), PC-ABS, ABS M30, ABS-M30i, ABS Plus and ULTEM 9085.

EBM Materials

EBM materials mostly are metal and metal alloys. The EBM material developed by Arcam manufacturer of EBM materials has developed various materials like Ti6Al4V titanium alloy, Ti6Al4V ELI titanium and ASTM F75 CoCr alloy.

LaserCUSING Materials

LaserCUSING materials mostly are metal and metal alloys. The LaserCUSING material developed by Concept Laser GmbH manufacturer of LaserCUSING materials has developed various materials like LaserCUSING CL 30AL (aluminum (AlSi12) powder), LaserCUSING CL 32AL(aluminum (AlSi10Mg) powder), LaserCUSING CL 40Ti (titanium

(TiAl6V4) powder), LaserCUSING CL 100NB (nickel-based alloy (Inconel 718) powder). LaserCUSING CL 20ES (stainless steel powder), LaserCUSING CL 50WS (hot-work steel powder), LaserCUSING CL 60DG (hot-work steel for die-casting powder) and LaserCUSING CL 91RW (hot-work steel powder). These materials are used in injection moulding mould making.

DLP Materials

DLP materials mostly are photopolymer. The DLP material developed by Envisiontec manufacturer of DLP materials has developed various materials like NanoCure RC25 (nanoparticle-filled Photopolymer), Perfactory R05 (photopolymer), Perfactory R11(photopolymer), Perfactory Y8 (photopolymer), Perfactory PIC-100T(photopolymer), Perfactory e-Shell 200 (photoreactive acrylate), Perfactory e-Shell 300 (photoreactive acrylate), Perfactory WIC100G Series (photopolymer) and Perfactory SI 500 (photopolymer).

Wax Jetting Materials

Wax Jetting materials mostly are thermoplastics and wax. The Wax Jetting material developed by Solidscape manufacturer of Wax Jetting materials has developed various materials like InduraCast (thermoplastics) and InduraFill (composition: natural and synthetic waxes and fatty esters).

3DP Materials

3DP materials mostly are thermoplastics, wax and composite powder. The 3DP material developed by 3D Systems manufacturer of 3DP materials has developed various materials like high-performance composite powder (ZP 130, ZP 131, ZP 150), model, acrylic plastic (VisiJet SR 200, VisiJet HR 200, VisiJet MX, VisiJet EX200), model (VisiJet DP 200), wax modelling material (VisiJet CPX200, VisiJet CP200).

PolyJet Materials

PolyJet materials mostly are photopolymer resins. The PolyJet material developed by Objet Geometries manufacturer of PolyJet materials has developed various materials like FullCure® 720, FullCure® 830, Vero White, FullCure® 840 Vero Blue, FullCure® 870 Vero Black, FullCure® 970 Tango Black, FullCure® 950 Tango Gray, FullCure® 930 Tango Plus, FullCure® 630, FullCure® 655 FullCure® 680 DurusWhite, FullCure® 430, FullCure® 980 Tango Black and FullCure® 850 Vero Gray [7–14, 44, 45].

Challenges for AM Process

AM technology has made significant strides over the past 27 years, but challenges are still having with this process. These are mainly related to materials and process. Related to materials, challenges are like materials characterization as needed on material properties for different processes, a database providing specifications of materials which includes mechanical properties data of available materials, as well as more detail on performance of fabricated parts made from these materials is very essential, need for developing additional materials and a growing demand is for developing testing procedures and methods of qualification to help expand the variety of materials available.

Related to equipment technical challenges are to develop method for process monitoring and control, to develop process understanding and modelling which includes development of new physics-based models of SLS processes to understand and predict material properties such as surface roughness and fatigue and it allows to predictive modelling, allowing designers, engineers, scientists, and users to estimate the functional properties of the part during design and pull the design to achieve desired outcomes, to develop machine qualification standards which could help machine-to-machine and part-to-part repeatability along with a standardized materials properties database, qualification at a machine or process level could help to reduce qualification time and effort. Related to the application the technical challenges are the development of new design Tools and software which allow users widespread access to, easy-to-use and affordable computer-aided design (CAD) tools at multiple levels. Solid modelling software is required to use SLS technology, and estimates of total solid modelling installations are surprisingly low from the four major suppliers of CAD solid modelling software.

For direct part production, new tools are needed that can simultaneously optimise both shape and material properties and the design complex lattice structures that optimise reductions in material and weight. For the non-professional markets, new web-based design tools could potentially allow non-specialists to creatively design products to meet their needs. New, web-enabled co-design environments would bring together the talent of professional designers with novice users to personalise designs.

CONCLUSIONS

Understanding of the material properties helps in proper selection of material satisfying the user requirements for specific application field. Development of more newer materials, material data base containing material properties and information related to the performance of fabricated part of chosen material, fabrication parameter and material properties relationship, process control and modelling and new design tool and software will increase acceptability of this technique with improvement in part quality, reduction in waste of material and total cost of fabrication of part In future, there is opportunity for fabricating high strength part with and without a tailored property at low cost which is possible with these techniques that may cover wide range of application areas. A discussion about future challenges to making SLS process more viable has been given. A detailed study to control specific characteristic needed to be studied further.

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