INJECTION MOLDING TO ADDITIVE MANUFACTURING – A TECHNOLOGICAL ADVANCEMENT IN PLASTICS 3D PRINTING

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There are many known techniques like Injection, compression, blow mouldings and extrusion, for processing plastics materials into various products. One of the most attractive processing techniques is injection moulding, utilized for auto bumpers and dash boards to small medicinal bottle caps. The growth and technological advancement for plastics injection moulding from manual process settings to fully automatic touch screen based electric injection mouldings have been established in last 20 years. One of the most preferable ways to produce plastics articles as it allows production of "more parts per hour ". Injection moulding technique is versatile for processing ABS, SAN, PP, PMMA, PS, PC, PA6, PA66, PBT, PET, PEI, PPS, PES, PAEK – nearly all thermoplastics. The technique has help to solve the challenges of application development in myriad industry segments like Automotive, Aerospace, Consumer Appliances, Electrical and Electronics, IT, Sports, Medical, Construction, Textiles, etc.

The global demand of products and application development work in Aerospace Industry, Bio medical, Oil and Gas, Advance transportations, Electric cars, Digital Consumer segment are growing rapidly. There are also challenges of product design, development and manufacturing exist in these segments. Large players in the segment like Boing, Airbus, NASA, Bio Medical OEMs, Auto OEM's like Mercedes, Rolls Roy's, BMW have taken the initiative to adopt the technology to solve the challenges in product design and application development to replace complex design metal parts to light weight plastics parts.

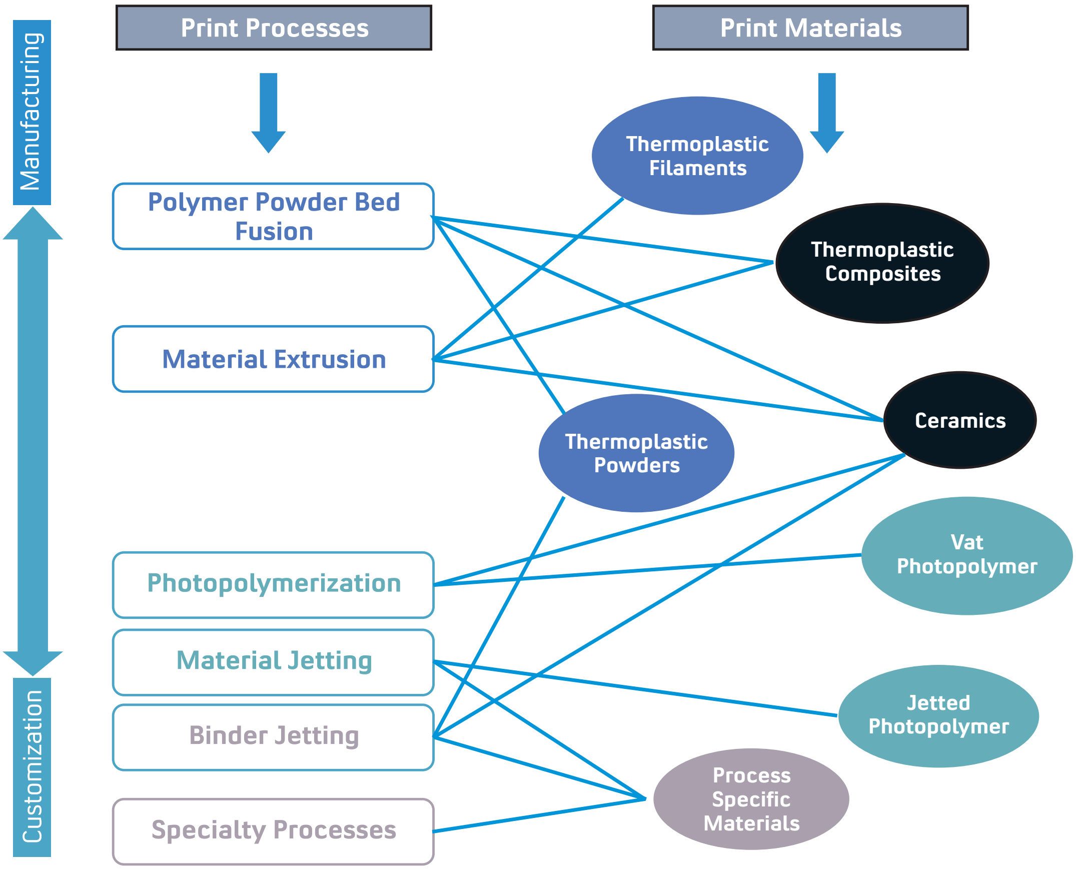
Industry sees it as a big challenge in plastics field with global digitalization and advancement in materials technology. It has given a new gift to the world of plastics processing known as "3D printing or Additive Manufacturing". 3D printing is most recent advance computerized technology enabling to solve the challenges of the advance segments and their future needs. The biggest challenge is to produce complex design parts, requiring good mechanical properties but light weight parts. Additive manufacturing, as known technically, has given birth to new advance plastics, and even metal, ceramics, processing technique to provide solution for the challenges existing in new immerging advance segments like medical and aerospace.

"The ASTM F2792 defines Additive Manufacturing (AM) as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies."

The new processing techniques by additive manufacturing available commercially in the market are 1) Polymer Powder bed fusion (Laser Sintering), 2) Material Extrusion- Fused deposition modelling (FDM), 3) Photo polymerization (Stereo lithography), 4) Material Jetting (Multi Jet modelling), 5) Binder Jetting (Powder bed and inkjet 3D printing).

1. Powder bed fusion / Laser Sintering: Thermal energy through laser selectively fuses regions of a powder bed layer by layer.
2. Material Extrusion/ Fused deposition modelling (FDM): Process in which material is selectively dispensed through a nozzle or orifice as filament and fused in selected shape.
3. Photo polymerization (Stereo lithography): A liquid

FIGURE 1 COMMERCIALLY AVAILABLE 3D PRINTING TECHNIQUES



photopolymer in a vat is selectively cured by light-activated polymerization.

4. Material Jetting (Multi Jet modelling): Droplets of built material are selectively deposited. Example materials include photopolymer and wax.
5. Binder Jetting (Powder bed and inkjet 3D printing): A liquid bonding agent is selectively deposited to join powder materials.

The additive manufacturing (AM) industry is predicted to maintain a strong growth rate over the next years and exceed $21 billion in sale of products and services by 2020, thanks to its capacity of continuous innovating and developing materials with better performance and broader range of applications.

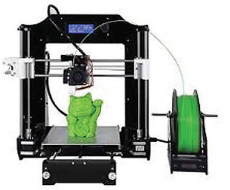
AM was first developed in 1986 in USA by Charles Hull, who established first company making models that, while highly complex, were mostly limited to prototype parts because of the durability issue of the resins used. Also, since specialized tool path programming was not required, parts could be made much faster. This is how the term "Rapid Prototype" became the primary name used to describe all types of 3D printing in the early years of development. It was only after the printed parts become on par with injection moulding for quality and cost, at least for small batches, that the name AM became popular.

The additive manufacturing has opened up doors for plastics raw material companies to think innovative and wide scope of research and developments work. There are global engineering plastics raw materials players like Evonik, & Arkema for Polyamide 12 & 11, CYTEK-Solvay for PEEK, PEKK & Polysulfones, SABIC for PEI, Gharda for PEKK are active for AM.

For polymers, the easiest and widely acceptable methods are " FDM Fused deposition modelling " and "Laser Sintering". FDM is much more popular to produce prototype articles, being less expensive and easier to handle. Whereas, laser sintering is more suitable for finished end products of complex designs. The Laser Sintering technology is approved by global aviation companies to meet their critical components need to replace metals from plastics.

Plastics industry is now exited to see the advancement of 3D printing by laser sintering and FDM technology. The story of 3D printing technology is also started in the same manner like Injection moulding semi- auto to complete computerized. The technology has started with prototyping product development with limited dimensions to now digital manufacturing system of finished product with desire strength without any requirement of mould or tools. This system also reduces the complex post moulding operation of machining of parts, reduced waste generation, assembly of different parts, logistic services, etc. All solutions now available in one system. Thanks to the company like EOS, 3D systems, Strategy, HP for their deep contribution and taking the lead in the field of Laser sintering and FDM, for both plastics and metals. EOS has launched various models like P800, P810, P500, P396 systems to process various engineering plastics. For FDM, companies like Roboze, who have developed advanced range of 3D printing machines, which can print high temperature plastics & its composites up to 400°C. FDM started with conventional prototype 3D printing of materials like PLA, ABS, PETG and now growth with adoption of high performance plastics composite materials like TPU, PC, PEI, PPSU, PEEK etc.

FIGURE 2: CONVENTIONAL FDM MACHINE



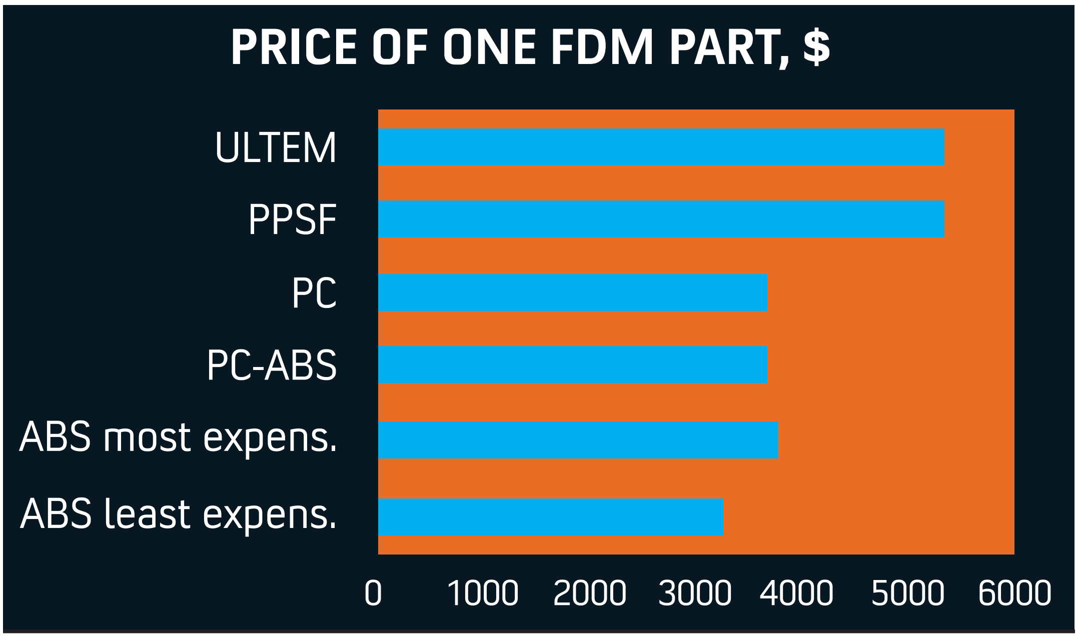
FDM process: The FDM process uses small diameter round filament as feedstock, fed from reels. In the printer, material is partly melted, and extruded through a heated nozzle, resting on a supporting platform if it constitutes the part's first and bottom layer. The nozzle moves to produce a one-layer thick cross section of the part in x and y directions. The material hardens immediately upon coming out from the nozzle [9]. When the first layer is completely fused, the building board is lowered in z-direction and the next layer is built on top. In this way a 3D geometry is created one layer (slice) at a time. Nozzle and platform move according to 3D-CAD data defining the part geometry. Due to the thermal fusion, the material bonds with the layer beneath and solidifies, forming a permanent bonding of two layers. The printer price range is $11,000- $500,000 (2014 prices). Plastics materials suitable for FDM today are ABS, PLA, PETG, TPU, PC, PEI, PPSU, PEEK & PEKK.

About Filament- The basic filament is prepared by extrusion in a special single screw extruder, with sizing die, cooling bath, dimension sensors, pulling devices, winding units. The typical filaments are round in diameter for FDM with 1.75mm dia. And tight tolerance of +/- 0.05mm. The basic material needs to have MFR in the range of 4 to 7 gm/10 min for better extrusion control. The cooling and extrusion rates are very important to maintain the diameter tolerances.

About Laser sintering - SLS printers first lay down a

FIGURE 3: PEKK FILAMENT FOR FDM

FIGURE 4: (SOURCE: BOEING)



thin layer of plastic powder. A laser impinging on it heats the powder and fuses it. This process of laying thin powder bed and fusion are repeated. The built up takes place with fusion with previous layers, and bakes the particles together by only fusing surface of powder particles in their "solid state", without melting the whole particles. Since SLS requires a precise temperature control, the scanning strategy and laser energy-input are carefully controlled throughout the process. The printer price range is $1. 3M to 2 M. Various plastics materials are in use are Nylon 11, Nylon 12, Carbon Fiber filled Nylon, PEI, PEEK, PEKK.

PEKK is gaining importance as the most suitable advance thermoplastic for Laser Sintering & FDM. It is thermoplastic with excellent mechanical properties retained at high temperatures up to 25ºC or more, with excellent chemical & hydrolysis resistance. The glass transition temperature - Tg of the various grades is 164-169ºC, and Tm is 305ºC. The biggest advantage of PEKK is very low melting temperature required up to 310ºC compare to commercially available PEEK, which has melting temperature of 335ºC making PEKK more readily processable than PEEK.

Recently "Gharda Chemicals Ltd" in India has also developed special PEKK material grades in powder and granular form, suitable for Laser Sintering and FDM technology. This PEKK is being evaluated by global aviation companies and medical companies to meet their critical upcoming challenging applications.

FIGURE 5: PEKK GRANULES

Since last few years' lot of advancement is happing in Laser sintering technology. More and more machine manufacturing companies are coming up with advance solutions, where the processing can be done by altering the laser settings to get better quality. In Laser sintering, there are advance process settings equipped to get good paths by altering layer thickness, Laser power, scan speed, hatching space, temperature, flow speed moving towards more digitalization This advancement demands updation of skill set and more knowledge of computer software. However, LS is a slow and very costly process, requiring several minutes to hours for making a single part so it is not likely that it can take over the injection moulding with rapid productions.

FIGURE 6: PEKK POWDER FOR LASER SINTERING

Fuel costs account for over 35% of airline's general operating expenses. This cost, along with increased fossil fuels cost, being a limited natural resource, have added pressure on aircraft manufacturers to deliver higher levels of fuel efficiency. The airline industry projects demand of around 35,000 new aircrafts over the next 20 years in order to replace ageing fleets and to meet civilian flight demands. This is a booming industry and airplane manufacturers need to step up their competitive advantage by ever reducing weight by replacing metals with plastics.

Engineers in the Aerospace Industry that are facing these challenges are seeking innovative technologies to develop fuel sipping, easily-assembled, and low maintenance aircrafts. One key to achieving this is with high performance polymers that replace metals, thermosets and can be found on more than 15,000 aircraft today. Those materials such as PEKK or PEI are able to withstand high mechanical stress, high temperatures and chemically harsh cleaning fluids. Plastics can be up to 70% lighter than metal, allowing fuel efficiency to improve immensely when changing in-cabin parts as well as for mechanical parts.

There is also wide interest shown by global biomedical OEMs to adopt Laser sintering technology to manufacture bio implant products, including spine, cranial and dental parts. There are required to be made in very specific size and shape and hence cannot be injection moulded nor can be readily machined to desire dimensions.

3D Printing or Additive Manufacturing is thus not only here to stay but also is rapidly growing novel technology bringing immense benefits to manufacture sector.

THE AUTHORS:

JAIMIN ZAVERI obtained his graduation in Chemistry from Gujarat University, Ahmedabad. Then masters in Polymer Science from SP University, Gujarat. He has worked, starting from 1996 in Plastics Molding Firms and then from 2002 to 2016 worked for multinational raw material companies like INEOS ABS (INDIA) Ltd , Lanxess, Covestro(India) Pvt Ltd (Formally Bayer Material Science Ltd, Bayer AG) at Key Positions in marketing and technical Services. Success fully handled various engineering plastics like ABS, SAN, PC, PC/ABS, TPU, PA6, PA66, PBT, PETG. He has successfully contributed to create new applications in industry sectors like Automotive, Consumer Electronics, E&E, Constructions, Lighting, Mass transport, Textile from concept to commercialization of application. Wide exposure of Institutional sales and Industrial marketing, Specification of product at reputed OEMS and Institutes. He has created many national and international key visible special projects in different filed of plastics.

He is now working with Gharda Chemicals Ltd and leading internal marketing and application development for high temperature and super high performance materials like PEK, PEKK, PBI, PEI. Helping Gharda Chemicals for marketing and application development to expanding the market of super high performance polymers.

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