3-D Printing of Plastics
The Emerging World of Digital Manufacturing

In a world where economies of scale matter less and less, mass manufacturing of identical items may not be necessary or appropriate. 3-D printing allows product customisation, lowers the cost and the risk associated with tooling and dies, says Dr. S. Sivaram.

One of the disruptive technologies to emerge in recent years in the plastics processing sector is the 3-D printing technology, also called as Additive Manufacturing (AM). This technology is growing at a very rapid pace and is termed as the first major revolution in manufacturing since the 'assembly line' concept that garnered the limelight in the late 19th century. Simply put, 3-D printing is nothing but 2-D printing performed repetitively. This technology has grown from the basic concepts of ink jet printing and stereo lithography. The process has made great strides in the thirty years since it was first reported[1] (Refer Figure 1).

This process involves a layer-by-layer assembly of materials to create an object using digital slices created by the software. As aptly stated by Professor Joseph De Simone[2], this technology is at the 'intersection of hardware, software and molecular sciences,' where plastics processing converge with IT to create a distributed manufacturing capability often termed as 'point-of-sale manufacturing'. AM has the potential to create 'just-in-time' flexible manufacturing with major changes regarding how we manage supply chains and inventories today.

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The technology is at a nascent stage and is loaded with possibilities. It is predicted that market for polymers suitable for 3-D printing is most likely to exceed USD 1.5 billion by 2019[3]. According to ASTM F42 Committee, AM processes can be categorised into seven classes by the type of materials used, the deposition technique and the way the material is fused or solidified. These are, powder bed fusion, photo-polymerisation, material extrusion, material jetting, binder jetting, sheet lamination and directed (or focused) energy deposition. As far as plastics and polymer composites are concerned, the most popular 3-D printing processes are selective laser sintering, stereolithography, fused deposition modelling and material jetting. Currently, ABS and poly (lactic acid) (PLA) are the two most reported polymers

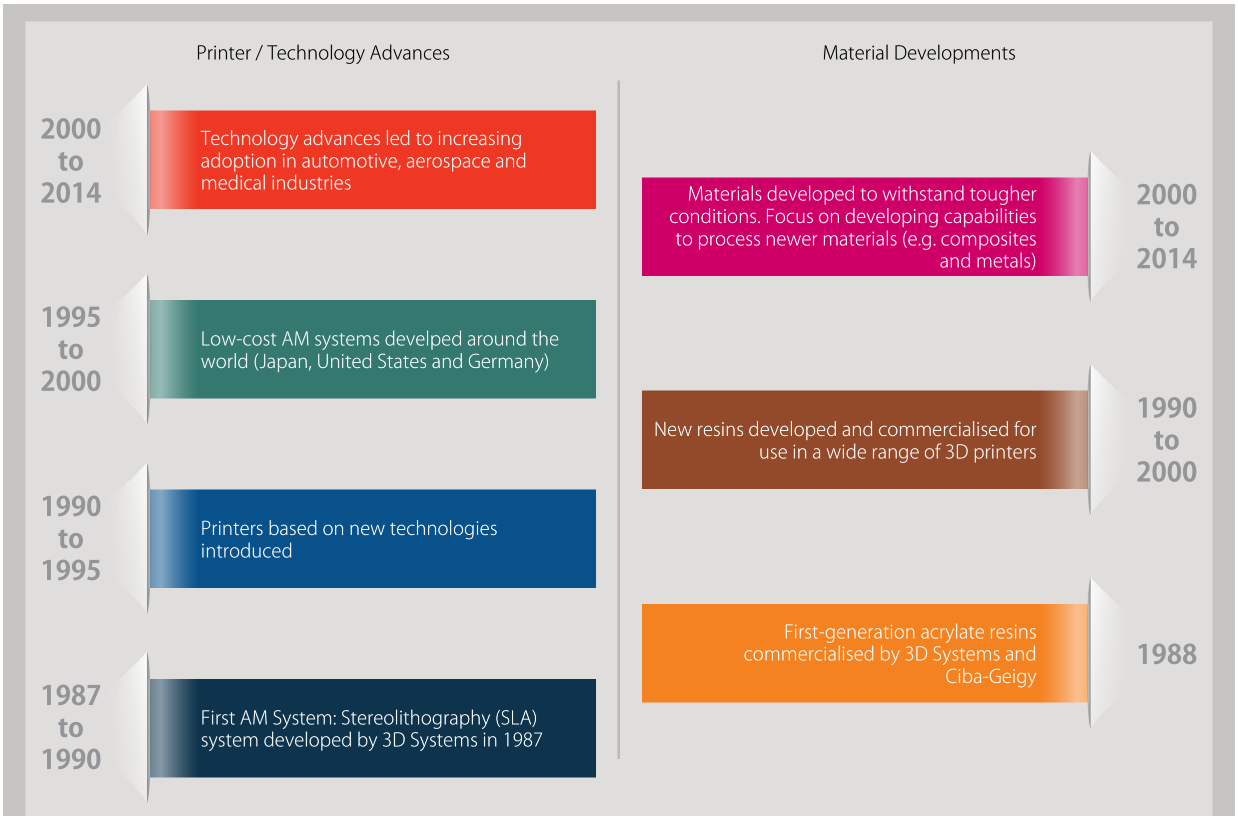

Figure 1: Additive Manufacturing and 3-D Printing: State of the Industry.

(Source: Deloitte University Press)

for 3-D printing. However, several other polymers can be used, namely, ABS-PC, PC, Nylon 12, polystyrene, polyacetal and PET. Another emerging area for 3-D printing is thermoset liquid oligomers which can be cured with light. Examples are multifunctional acrylates, epoxy-acrylates, urethane acrylates functional silicones and a variety of photo-curable reactive oligomers. Thermoset 3-D printing involves three steps, namely, pre-processing where a software is created to calculate the placement of the liquid reactive oligomer on a support material in a 3-D CAD file, production, where UV cures the jet of liquid droplets of the reactive oligomer, causing the layers to accumulate on a build tray to create the object followed by support removal by hand or using water.

The excitement of the application of AM to polymer processing is due to the ability to produce complex parts without moulds or need for assembly, possibility of local texturing, ability to produce functionally graded materials and unlimited freedom for product design.

Progressive Developments

However, AM is mostly employed today for prototypes, models for form, fit and function, and non-load bearing parts and therefore limited to high value, low volume customised components. However, it is believed that continuous development in technology will make AM competitive with other manufacturing technologies that have been perfected over a century and move beyond mere prototyping applications. The vitality of this area is evident by the fact that from a mere 80 issued patents in 2005, over 600 patents were issued in 2013 on AM technology[4].

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3-D printing allows product customisation, lowers the cost and risk associated with tooling and dies. In a world where economies of scale matter less and less, mass manufacturing of identical items may not be necessary or appropriate. Consumers are becoming choosier and have a desire to be different. The day is not too far when they will download designs of products they need from the web, very much like they download music or video today, print them at home or send the design to a neighbourhood 'print shop' electronically and get the product printed and delivered at home. The closest analogy is the neighbourhood 'tailor' who makes clothes to fit your size. Mass manufacturing made readymade garments cheaper; but imagine, if for a moment you had an option to send the garment designs electronically to a 'digital tailor' from whom you can get the dress made in hours!

The objects you can get printed are endless, limited only by one's imagination; shoes, toys, jewellery, dress and objects of art. Another emerging area of interest is to use post-consumer waste plastics as feedstock for 3-D printing. However, the sector where 3-D printing will make the most impact is in medical implants and prosthesis. By definition, such products have to be customised to suit a person's physiology or anatomy. Medical implants, dental and orthodontic applications, hearing aids, optical eye lenses and body parts for implants are all ripe for 3-D printing technology. The US hearing aid industry migrated to 100% AM in less than two years, wiping out all the traditional producers! Digital dentistry is already here. A 3-D printer can produce 450 dental crowns, each tailored for an individual patient, in one day', contrast this to the conventional method of production which would have consumed 40 days.

About 20% of output of 3-D printers is used today for manufacturing, while balance for rapid prototyping of functional parts. It is anticipated that by 2020, 50% of the output will be for parts manufacturing[5].

Technology Challenges in AM

Many challenges to AM technology still remain to be addressed. There is a need to extend the range of polymers that can be printed. Most of the polymers used till date have been amorphous polymers which show little shrinkage on cooling. There is a need to understand and minimise stress induced shrinkages in semi-crystalline polymers to render them suitable for printing. It will be useful if pellets can directly be fed to printers instead of the filaments that are used presently[6]. Filaments are at least ten times more expensive than pellets. Ability to print powders, semi-solid and solid starting materials e.g. excipients, starches, polyethylene glycols, sugars, food-based starting materials, biodegradable polymers etc. could open up new opportunities in food and pharmaceutical industry. It is conceivable that custom-designed personalised dosage forms, such as tablets, could be 3-D printed and made available to patients.

Additionally, 3-D printing process is still too slow; they show high variability from part to part and lack versatility. Materials and machines are often bundled and marketed by companies, tying a machine with proprietary products. Layer by layer deposition has the potential to create defects in structures leading to loss of mechanical properties.

Early stage technologies are now emerging which show promise to make 3-D printing faster by 100X, even 1000X. The Continous Liquid Interface Production Process – CLIP[7] is one such process which has attracted widespread attention in the press. Carbon 3D is a start-up company formed to take this discovery into commercial applications. Another development is the high speed sintering system of infrared absorbing ink droplets that has been sprayed on powder using lasers[8].

Industry Today and Tomorrow

AM technology is at a point where World Wide Web was in 1995. So, the rate of pace of growth of this technology is certain to surprise us. Robotics along with AM will push the world increasingly towards digital manufacturing and 'people-less' production[3]. The plastics processing industry has to connect into the emerging commercial and IT ecosystem, upgrade their skills and technology capabilities, and be ready to embrace the technology. Polymer manufacturers have to learn to tailor resin properties compliant with the needs of this industry. The polymer science research community has to make available a wide variety of resins and additives that will be needed for AM and address some of the deficiencies in technology.

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Dr. S. Sivaram will periodically address in this section, contemporary issues and developments in polymer science, technology, industrial applications and public policy with a view to inform, educate and engage in discussions.