MULTI-JET FLUID DEPOSITION IN 3D PRINTING: A REVIEW

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ABSTRACT-The use of multi-jet technology for fluid dispensing has a great potential for research in 3D printing which can result into a phenomenal commercial success. Currently inkjet technologies are being used for 2D and 3D printing which are sophisticated multi-jet fluid deposition technologies. Multi-jet technology ensures the speed of the process which makes it fit for manufacturing on an industrial scale. On material side there are various options available like regular photopolymers, waxes, flexible or hard polymers, rubbers, PEG, etc. along with novel materials like water, ceramics, alcohols, etc. This study covers multi-jet deposition of fluids, so deposition of gases has also been discussed which is a new area altogether for 3D printing. Emerging applications like sand 3D printing and ice modeling are also based on multi-jet fluid deposition technology. The ice modeling opens up a new segment in the 3D printing area if the technology can be exploited commercially. As advantages of the technology are discussedthe limitations are also focused in this work. If these limitations are overcome, research on more advanced and frugal technologies is required. Approach for the same is mentioned. Finally, the conclusive remarks highlight the future scope for the multi-jet dispensing technologies which give an insight about the areas that are yet to be explored and have a great potential to churn out commercially exploitable technologies.

KEYWORDS: **Multi-jet Fluid Dispensing, 3D Printing, Liquid 3D Printing, Gas 3D Printing, Ice 3D Printing,**

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1. INTRODUCTION

1.1. Overview of Multi-jet Fluid Dispensing Technology

The technology of *multi-jet fluid dispensing system* is used extensively in the printing systems. Printing related industries like textile, hoardings, book-printing, etc. rely on such systems. In fact, the importance of the inkjet printing process was highlighted when the process started to emerge for commercial exploitation during 1970s. Recently, when 3D printing came up as a novel technology being part of additive manufacturing domain, the same principles of 2D printing with inkjet were utilized to create systems which could print objects in 3 dimensions. Today, the technology of 3D printing is being called the disruptive technology of this era. Thus, it is important to look at this technology since its inception stage to gain insight about how the technology was developed. This could help in discovering the unexplored areas with a good research potential.

1.2. Invention of Continuous Ink Jet (CIJ) Printing

As mentioned in their article by Simon James Ford et al, early scientific breakthrough was made in continuous inkjet (CIJ) at the Stanford Research Institute by Richard Sweet in 1960s. It was commercialized by Cambridge Consultants Ltd (CCL) in the UK along with the printing firm A.B. Dick Company in Chicago, IL. [1] The technology of CIJ involved using a nozzle which continuously fires the jet of conducting ink which is deflected to its desired position using the electrostatic field. The ink which is not deflected can be deposited back to ink reservoir with the help of a gutter. It is used for printing in packaging systems even today for marking the codes on products since with this technology; printing on high speed, cylindrical objects is possible. Domino is a CCL's spin-out for code printers.

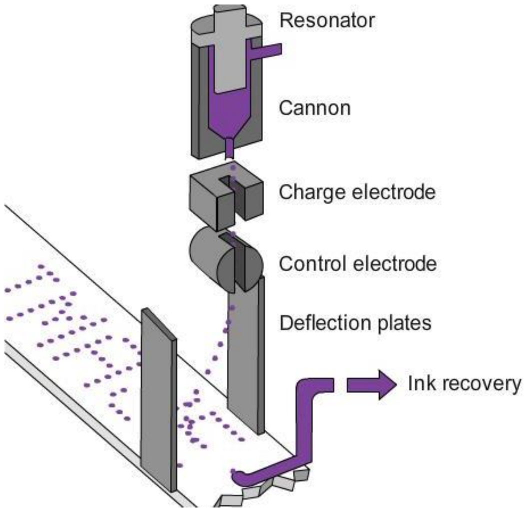

Fig. 1 Schematic Representation - Continuous Inkjet (Courtesy - EDF System Integration)

1.3. Invention of Piezo and thermal based Printheads

In 1990, Xaar came up with commercialization of piezoelectric Drop on Demand (DoD) based printheads. The technology for piezoelectric printhead was developed by Kyser and Sears in 1970s at Silonics. In the printhead, there are small chambers which are actuated by a piezoelectric action. The ink is contained in these chambers. As a response to external voltage, piezo element undergoes volume expansion quasi-adiabatically. It sets up a shock wave in the chamber with reduction in chamber volume. Due to shock wave, the required amount of ink is ejected from the nozzle. (Madhusudan Singh et al) [2] Piezoelectricity based printheads can work with a variety of inks such as solvent based, aqueous based, UV inks, etc. It is the most versatile technique for printing.

Hewlett Packard's thermal print head was a breakthrough in printing technology. In this type of print head, a chamber is filled with ink; a heating element present close to the ink suddenly vaporizes the ink creating a vapor bubble inside the chamber. As bubble collapses, the ink is ejected out from the chamber through guide elements. By precisely positioning such chambers and firing them in an order, ink can be deposited in the required pattern on the substrate. (US Patent: 4789425) [3] Thermal printheads are cheaper as compared to their piezo counterparts. But the versatility of the ink material available with piezo printheads is not there in thermal based printheads. Thermal ink dries quickly as it is deposited on the substrate. All paper based printing is carried out using thermal printheads.

Inkjet technology was primarily being used for printing on 2 dimensional substrates. In 1984, the first patent for 3D printing technology using inkjet was filed by Chuck Hull of the 3D Systems Corporation. The technology was named as stereolithography. In this technique, layers are added by curing photopolymers with UV light lasers. The strategies developed for slicing and filling the area are still used today. [4]

In 1993, MIT came up with a ground breaking research in the field of 3D printing technology. (US Patent: 5590244A) The part to be printed is sliced in the 2D cross sections. It uses the powder bed of the model material. The process goes by building cross-sectional portions called as slices from a three-dimensional article, and arranging and joining the individual cross-sectional areas in a layer-wise fashion to form a final article. The individual cross-sectional areas are built by using an inkjet printhead to deposit an aqueous solvent to an adhesive particulate mixture, which makes the particles of the mixture to adhere together, and to previous cross-sectional areas. This technology was commercialized by Z Corp (now known as 3D Systems Inc.) [5] This product also underlines the development of two different materials – build material, which is a model material and binder material, which binds the particle of build material together. Several build – binder materials were used in this type of 3D printer. Earlier, only photocurable polymers were being used. But with the 3DP developed by Z Corp, powder of different materials, even metals were being used to model the parts.

1.4. Development of 3D Printing Technology with Multi-jet

Stratasys commercialized the technology called Fused Deposition Modeling (FDM) in which a filament of plastic was extruded through a heated nozzle and deposited in the desired shape by nozzle movement (1992). To support the overhanging section of the model, the support was required to be given. Thus it made the distinction between model materials and the support materials. Since the support was expendable, the support material had to be weaker and cheaper than model material. Thus, waterworks came up with a material which was soluble in alkaline solution.

Objet 3D printer (1988) developed by Israelis uses the polyjet matrix technology, in which the model and support material are printed at the same instance using a multi-jet print head. The model material is the photocurable monomer and the support is in the form of a gel – like substance which can be washed away with a jet of water after the part is completely printed.

As inkjet based 3D printing technology emerged and started being developed looking at commercial market, the need for research on different materials and their properties became more of a topic of interest. Thus for inkjet printing, the materials can be broadly classified into model materials and the binder/support materials. The materials are elaborated in the coming chapters. In this report, the emerging technologies are also elaborated. The technologies which are in their ideation stage and are being followed for their validation are included in the subsequent chapters in this report. Gas printing, printing with ice and photopolymer simultaneously, multi-jet wax printing are discussed in the subsequent chapters.

2. MULTI-JET FLUID DISPENSING

1.1. Classification of inkjet technologies [6]:

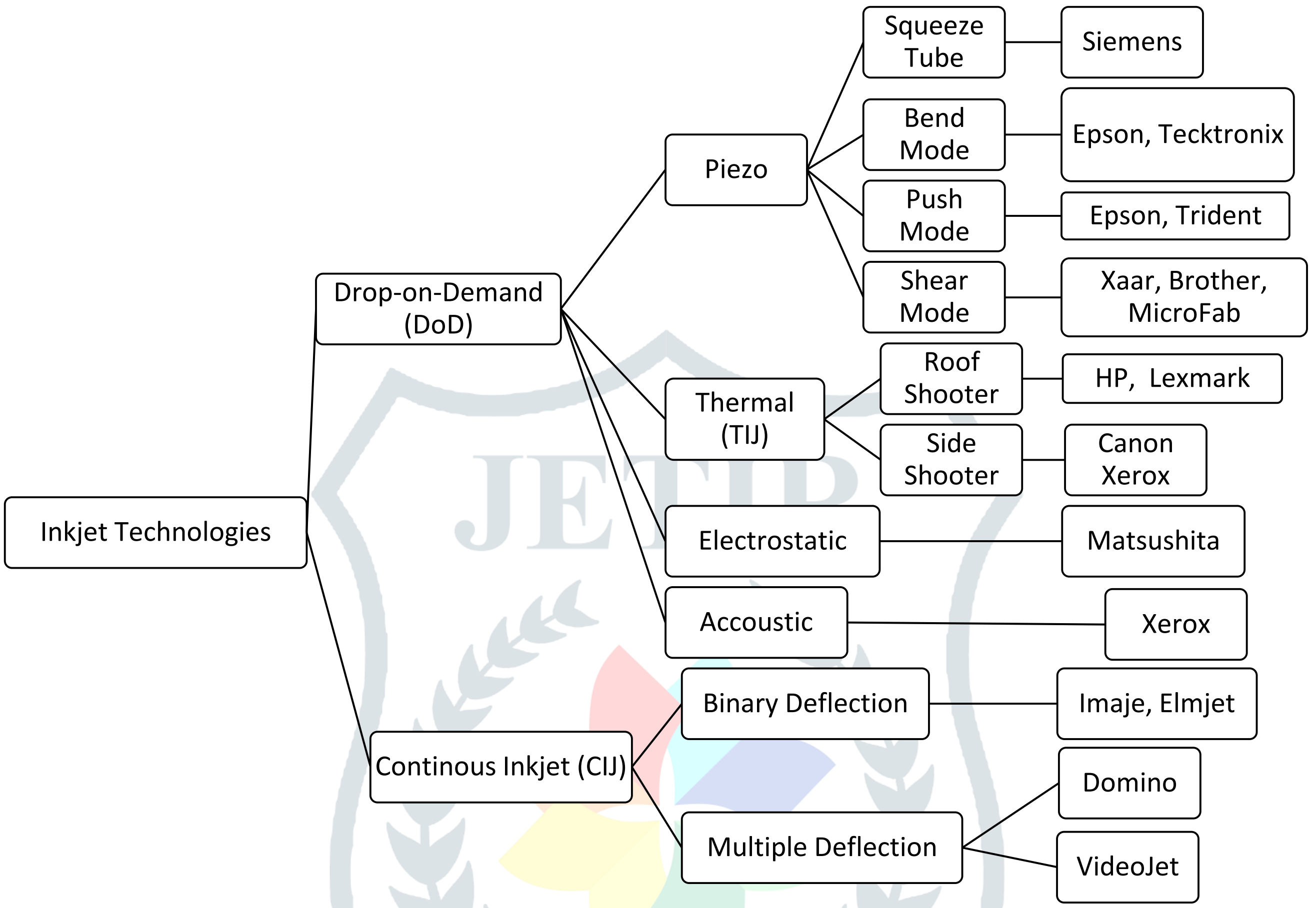

Fig. 2 Classification of the Inkjet Technologies

1.2. Continuous inkjet (CIJ)

Continuous inkjet technology can be classified into two categories. Namely binary and multiple deflection system. In binary deflection system there are two states of the drops, charged or uncharged. The charged drops are deposited on the surface to be printed and uncharged drops are deflected into the gutter. From gutter they are recirculated through the ink tank again in the system. In multiple deflection system, charged drops are deflected at different levels and deposited on the surface. Uncharged drops are recirculated. Both the methods are equally popular. Companies such as VedioJet, Domino, Imaje, etc.have been developing and commercializing this technology. [6]

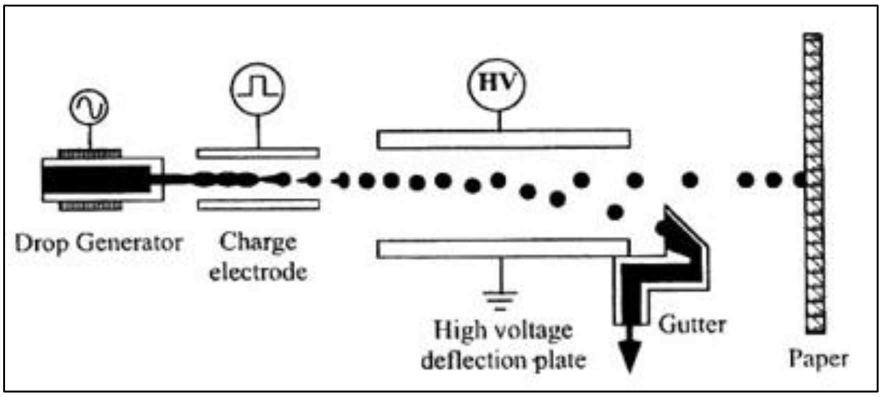

Fig. 3 Continuous Inkjet - Binary Deflection System (Courtesy - Hue P Le et al.)

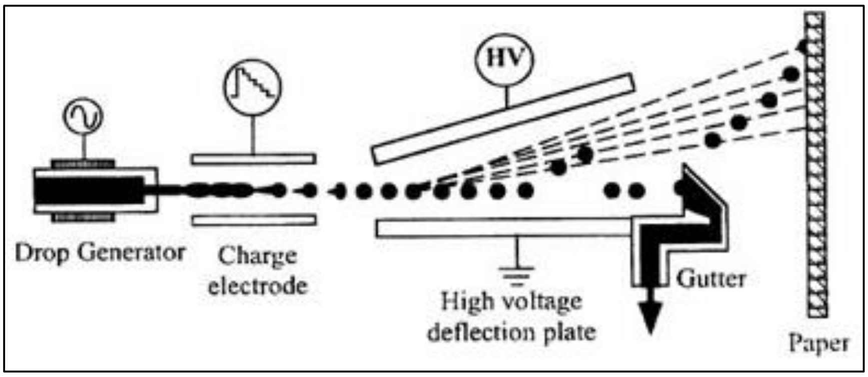

Fig. 4 Continuous Inkjet: Multiple Deflection System (Courtesy - Hue P Le et al.)

1.3. Drop-on-Demand (DoD)

Drop on demand is a popular technique in inkjet printing. It can be classified into 4 categories namely thermal, piezoelectric, electrostatic and acoustic inkjet. But most popular out of these are thermal and piezoelectric technologies.

- **Piezo**

A glass or plastic nozzle is surrounded with piezoceramic in squeeze mode inkjet. This was used first in Siemens PT - 80 inkjet printer. There are two designs namely bend mode and push mode. They are shown in Fig.5. In bend mode, the ink comes in contact with piezo element in a bent channel and in push mode, there is a piezoceramic rod which expands pushes the ink out of the chamber by vibration. To prevent any harmful interaction between ink and piezoelectric element, a thin film is provided in between.[6]

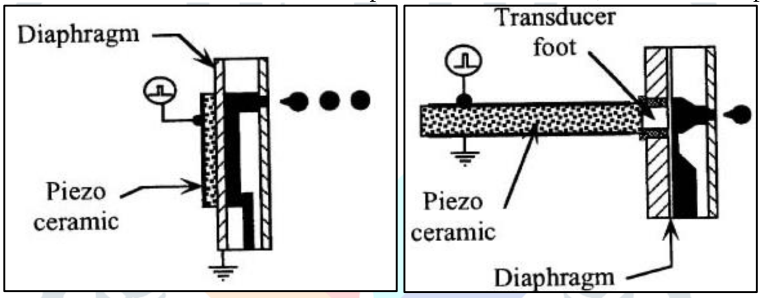

Fig. 5Piezoelectric Printhead: Bend Mode (L) and Push Mode (R)

- **Thermal**

Thermal is an economical and quality method for ink deposition. Thus, even it was invented after piezoelectric method, it is one of the most successful methods today for ink deposition through multi-jet. Fig. 6 shows there are two types of the thermal inkjet. Roof shooter and side shooter. [6] The types are made based on the jetting direction of the ink. Roof shooter is used in printheads from HP and side shooter configuration is used in Canon and Xerox. [6]

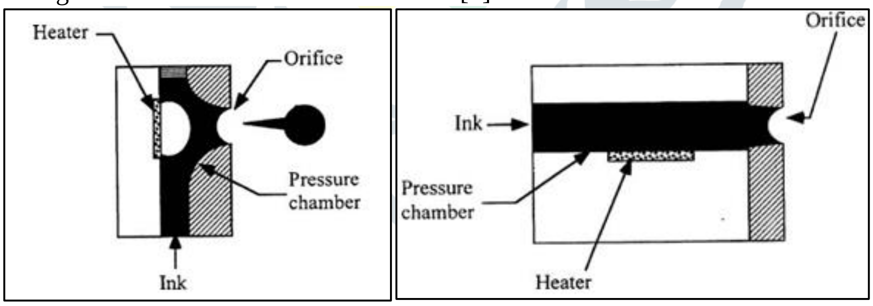

Fig. 6 Thermal Printhead: Roof Shooter (L) and Side Shooter (R) [6]

1.4. Process of Printing and process Parameters to control precision

1.4.1. Resolution [7]

Fig. 7Image of a circle at various resolutions (Courtesy - LEFA Prints)

- **Pixels per inch of an image (PPI)**

The sharpness of an image on the screen is denoted by PPI. Less the number of the pixels per inch, more they appeal to the eye. This creates a pixelated output which is an inferior grade image.Although images which are to be displayed on screen are allowed to have low resolution (the optimal is 72 ppi), the images to be printed need to have a high resolution (optimal is 300ppi) to be printed on a surface with appropriate size.

The PPI becomes a serious concern while creating the images. The images with higher PPIs can be compressed and their PPI can be reduced but the images which are created only for screen viewing are with low PPI and it is not possible to alter it and add more pixels to it.

- **Dots per inch of a print (DPI)**

If there are more drops of the ink per inch, the quality of the print is higher. Minimum value of the DPI for a good quality print is 200 dots. Higher DPI ensures the sharpness of the image. Various colors can be printed using different jets with a resolution higher than 200 DPI. For premium quality images, the minimum DPI that is required is 300.

1.4.2. Droplet Size

There is a printing color scheme called hexachrome. It comes with CMYKOG colors (Cyan-Magenta-Yellow-Black-Orange-Green). It is used for more precisely colored images. But with the variable drops technique, the size of the drops can be adjusted in such a way that more color combinations are possible with CMYK configuration. Thus, this variable drop technique is popular, making hexachrome scheme obsolete now. In this technique, large areas are covered with higher droplet size and areas with sharp line are printed with small droplets. [8]

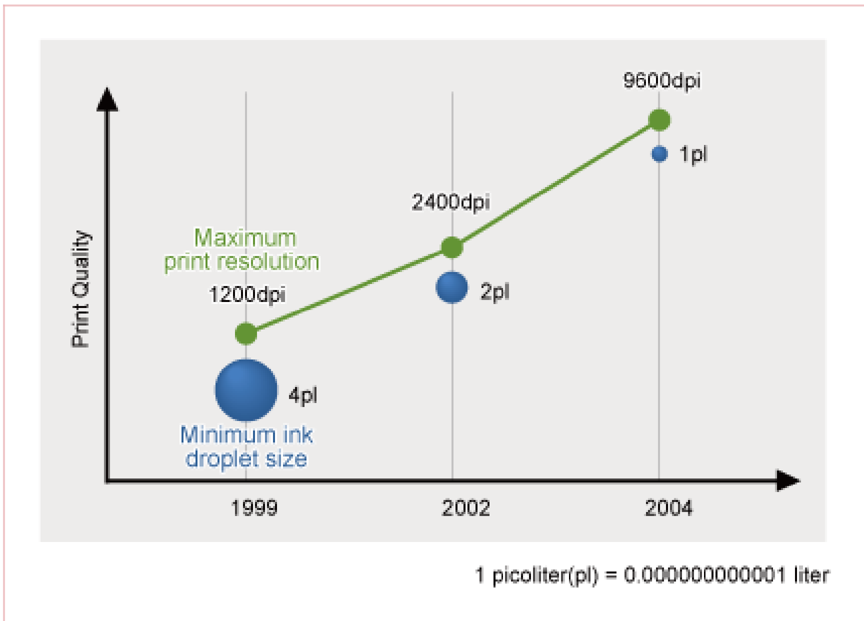

Fig. 8 Print Quality vs Droplet Size (Courtesy - Canon Ink Technology Guide)

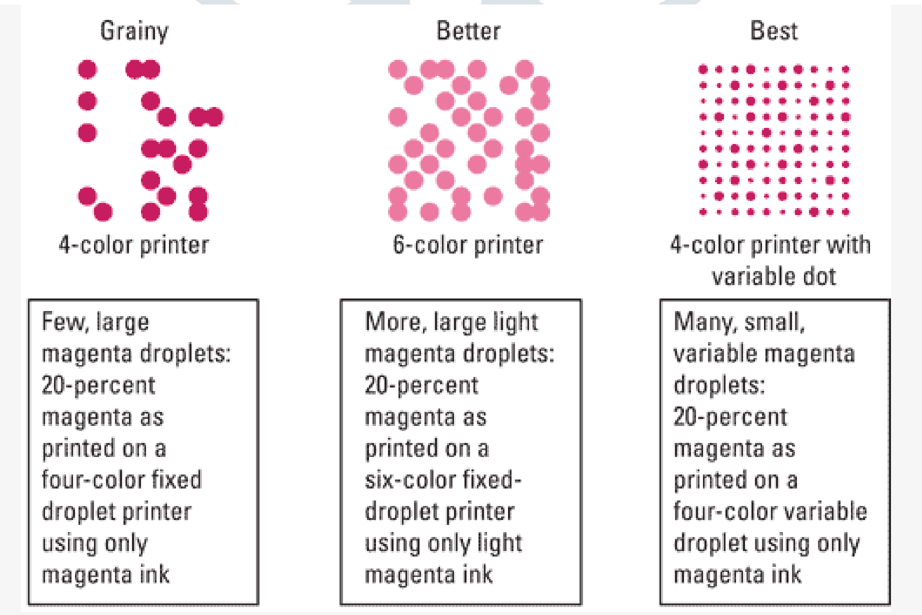

Fig. 9 Variable Dot Printing Technique

Photo. 1 4-Color Printer with Variable Dot Printing (Courtesy - Sign industry magazine)

1.4.3. Frequency

Frequency is an important factor to create the droplets from the stream of the ink. The wavelength λ of the perturbation created by certain frequency *f* in the stream should be greater than 3.13 – 3.18 times the nozzle diameter. [9]

$$f = \frac{V_{print}}{\lambda}$$

It has been found from the data archives of the Meteor Inkjet Technology, Inc., a UK based firm, for a stable jet formation of drops, wavelength of λ = 9 times the radius of the nozzle. To create a sufficient perturbance, the appropriate frequency has to be selected. The frequency also determines the accuracy and the print speed as mentioned by the following equation [10]–

$$f = DPI \times V_{print}$$

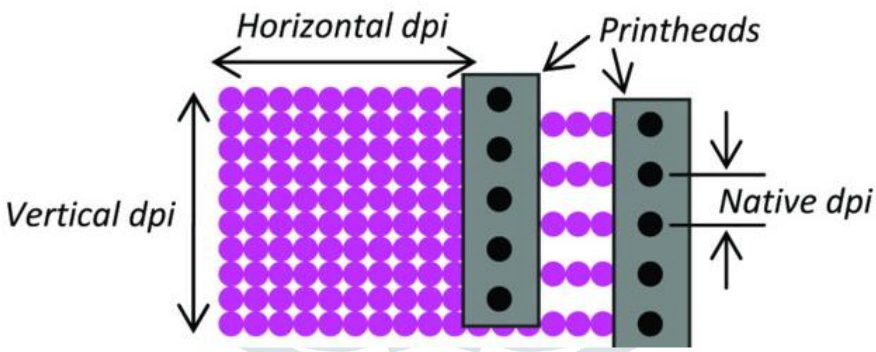

Fig 10 Diagram representing relation between frequency, DPI and printing speed

1.4.4. Ink viscosity

In a study published by journal of applied mechanics and materials, the correlation between edible ink viscosity and printing speed has been given. In that paper, Jingmei Sun et al state that as viscosity goes on increasing, the roundness of the droplet increases with increase in the viscosity up to a certain viscosity value, and after that it again becomes elongated with a tail. [11]

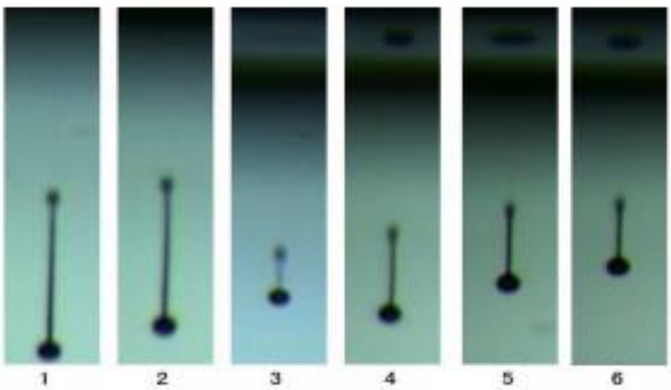

Fig. 11 Changes in the drop size as viscosity increases from 1 to 6 [6]

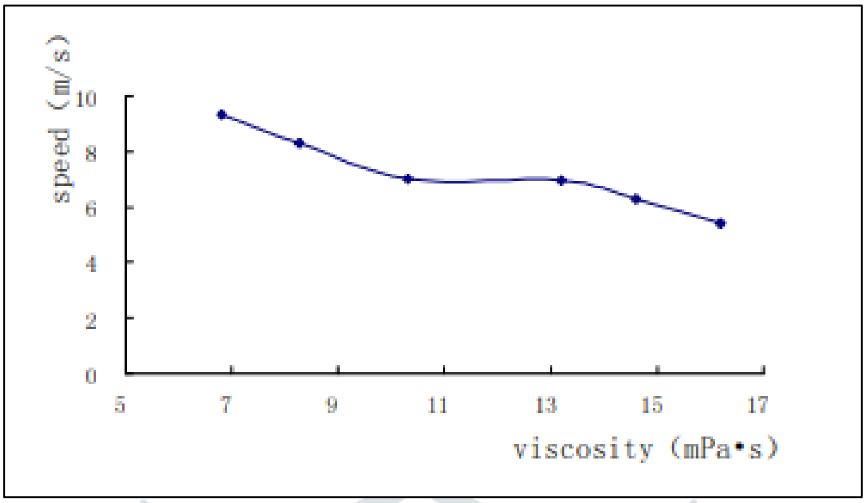

Fig. 12 Effect of Viscosity on Drop Speed

From the graph it can be seen that with increase in the ink viscosity, the droplet speed goes on decreasing. It means that the printing speed also goes on reducing as the ink viscosity increases from 6 mPa.s to 16 mPa.s.

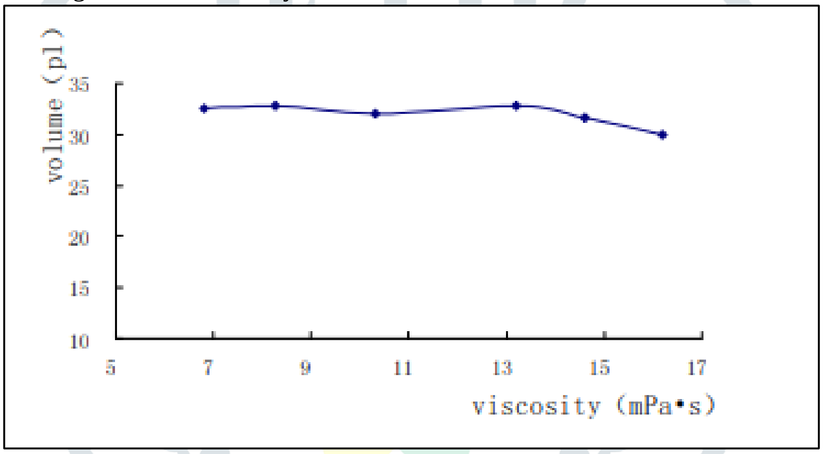

Fig. 13 Effect of Viscosity on Drop Volume

Drop size remains unaffected with increase in the viscosity of the ink. The reason being the speed with which the drop is ejected reduces. Thus, the amount of the ink contained in a drop remains the same.

1.4.5. Surface Tension

Surface Tension plays an important role in determining the performance of the inkjet printer. In fact, surface tension, jetting velocity, nozzle diameter, and material density all these parameters play a key role.

An important relationship between the Reynolds number and Weber number exists in case of defining surface tension. Where Reynolds number is Re, (ρvd/μ) and Weber number iswe, (ρv^2 d/σ); ρ is the density of the ink. The variables v, d, μ and σ are the droplet velocity, droplet diameter, liquid dynamic viscosity and liquid surface tension, respectively.

Condition for DoD jetting [12] –

$$1 < \frac{Re}{\sqrt{We}} < 10 \text{............eq. 1}$$

4.3. BINDER MATERIALS

In a process called binder jetting, a binder which is glue-like material is deposited on the powder bed using the multi-jet print heads. The process of deposition and powder spreading goes on successively in order to bind powder layers together and create a part. Generally the powders are gypsum based composites. After printing an object, it is coated with resins to make it robust. With this technique, various powders can be used to make a single object, also colored objects can be printed using different colored binders. A good bandwidth of materials like plastics, sand or metals can be printed with this technique. [13]

After printing, the part needs to be cured or sintered. For some materials, parts are infiltrated with other materials to make them strong. HIP, i.e. Hot isostatic pressing is also used for compacting the parts to impart them a high density. [14]

In principle, binder jetting uses the same concept of paper printing. For every layer, binder is deposited in the required shape. After combining all the layers, the part is constructed. Very large objects – like room sized structures in architectural purpose can be printed with this technique. This is the best option for 3D printing since it creates solid layers. [14]

Another benefit in binder jetting is the part is built with just adhesive properties. There is no process which heats the part unlike FDM, laser sintering, etc. This avoids thermal stresses in the process. Thermal stresses create many problems like distortion, cracking, etc. Thus, it becomes extremely necessary to relieve these thermal stresses. Processes of stress reliving are required to be performed separately. There is no requirement of support structure as well since the unbound powder works as a support. This powder can be reclaimed later on. This process is also more economical than that of other additive manufacturing processes. [14]

3.1. Classification of Binder Materials[15]

3.1.1. Binders for Starch and Polymers

To create the inter-diffusion in the polymer, solvent is used in such a way that it increases the volume of the powder by creating swelling – like effect. There are two types of polymers viz. hydrophilic and hydrophobic. Plaster, cement, starch, etc. powders are hydrophilic, thus aqueous based solutions are used as binders. Hydrophobic polymers use organic solvents like chloroform. Polymers are polylactic acid (PLA), poly(Lactide-co-glycolide) (PLGA), etc. are hydrophobic in nature. [15]

3.1.2. Binders for Ceramic and Metallic Powders

Ceramic and Metallic particles use aqueous as well as non – aqueous binders. These binders contain silica silver nitrate, etc. particles. These type of binders create a film over particles and when they get dry, they strongly adhere to the particles.
Samuel Clark Ligon et al mention that for hydroxyapatite (HA) powders, 25% citric acid can be used, thus HA scaffolds for bone tissues can be prepared. Reactive resins like furfuryl alcohol etc. make good non – aqueous binders. [15]

3.1.3. Embedding Binders with Powder Materials

Aqueous binders are used with water soluble additives like Poly Vinyl Alcohol (PVA), starch, plaster, cellulose derivatives, etc. To achieve the binding, powder form of the above materials are mixed with the powders when they are spread on to the work table for 3D printing. By depositing the solvents by multi-jet techniques, the powdered binders can be activated. This has an advantage. The problem of nozzle clogging while depositing the binders can be avoided completely.[15]

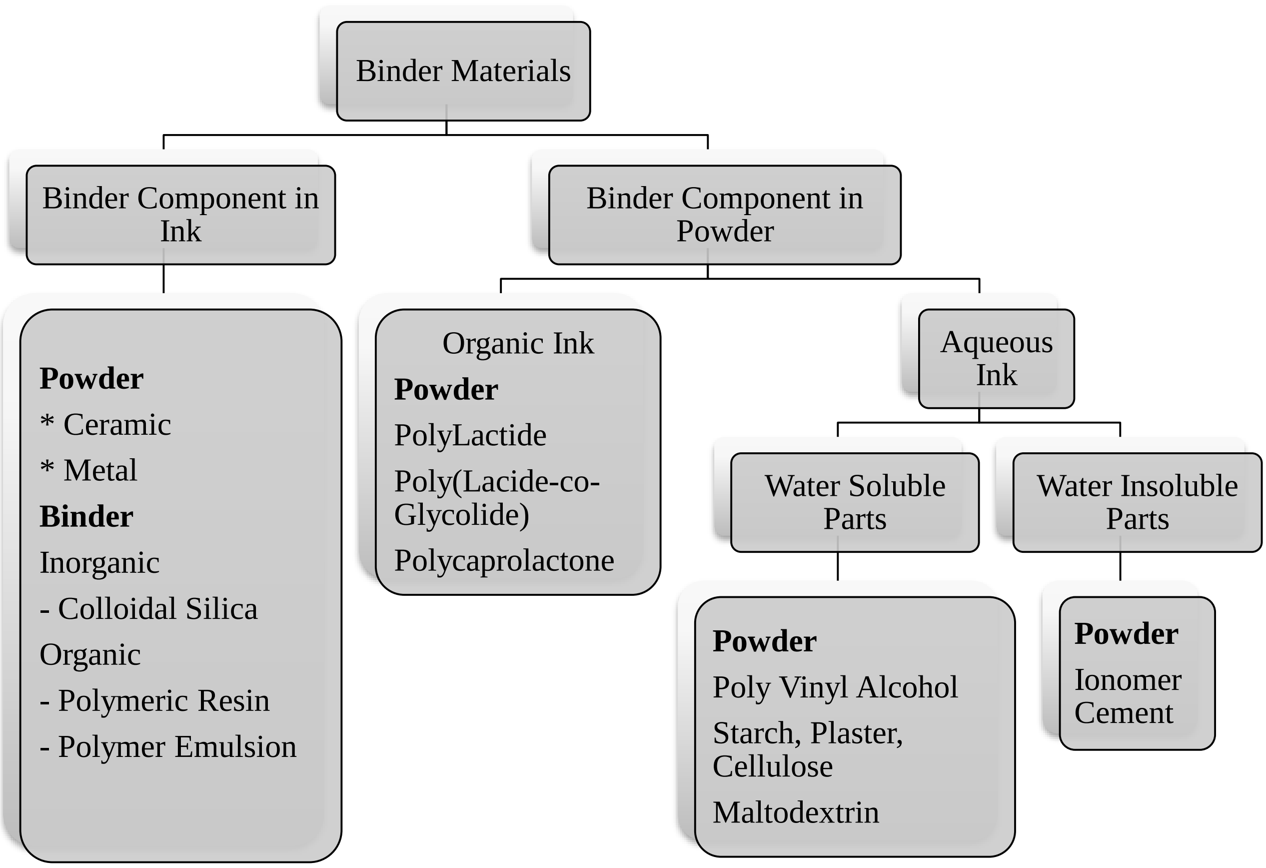

Fig. 14 Classification of Binder Materials

3.2. Post-processing of the Parts by Binder Jetting

The parts which are made by 3D printing using aqueous inks are vulnerable to moisture in their green state. By absorbing moisture, the powders tend to "swell". Since the swelling occurs in non – uniform way since only outer surface is exposed to moisture, they tend to crack. To avoid this, green parts are infiltrated with resins such as cyanoacrylates. In other approach, polycarboxylate ionomers and zinc oxide are blended with base powders. As soon as aqueous binders are printed, zinc ionomers are formed. It is called ionomer cement. They show better mechanical properties and structural precision.[15]

~~5.~~4. Build Materials

Build materials are broadly classified as model material and support material. Model materials are the ones with which the parts are made and support materials are required to support the geometrical features which are overhanging. Unlike photopolymeric vat methods, the multi-jet based systems need completely dense support structure. Thus the material requirement is equal to the build volume of the part. Because of this, one advantage is that the multi-material objects or multicolored configuration is easy to make. Disadvantage is that there are limitation on the deposition due to surface tension and viscosity of the parts.[15]

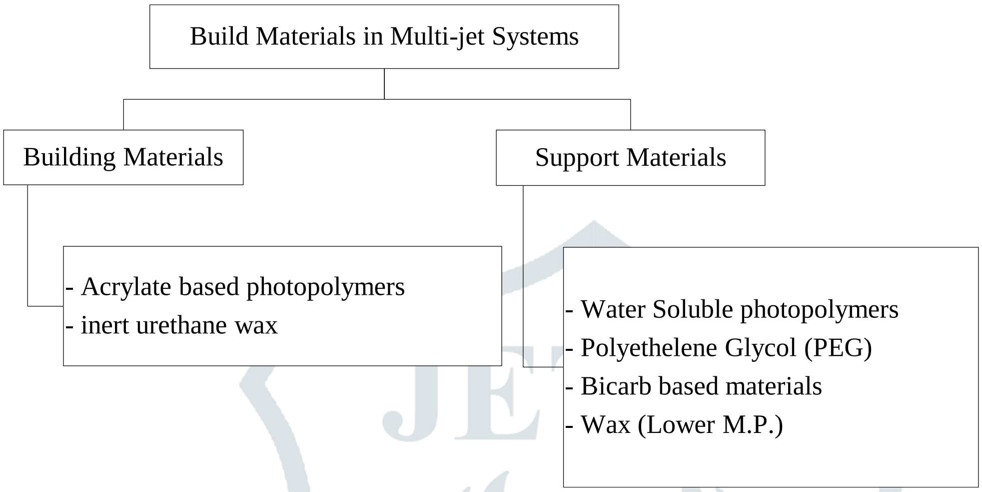

Fig. 15 Classification of Build Materials

4.1. Materials used in Multi-jet Modeling (MJM) – 3D Systems

The technique of multi-jet modeling works similar to inkjet printing. The company's ThermoJet model is used for wax parts. In this model the parts which are having up surfaces are made with good accuracy, however the down surfaces are not having good surface texture due to the removal of support structure.The technique of multi-jet modelling uses the soluble support structure which can be washed away. [16]

There are various materials offered by multi-jet modeling which are VisiJet materials as a commercial name given by the company. They are available in various colors, texture and the mechanical properties.These materials can be used as per their functionality. [17]

Table 1. Properties of the Materials used by MJM [18]

S No	Parameter Range	Regular Material	Rigid Material	Soft Material
1	Tensile Stength	30 – 35 Mpa	35 – 45 MPa	0.2 – 0.4 MPa
2	Elongation	20 – 30 %	6 – 12 %	160 – 230 %
3	Impact Strength	20 – 25 J/m	40 – 50 J/m	NA
4	Shore Hardness	60	77	28 - 32
5	Distortion Temperature	43°c	51 °c	NA
6	Colour Options	Gray, White	Black	Translucent

4.1. Materials used in Polyjet (Stratasys – Materialise):

Stratasys and materialise have come up with materials which are proprietary photopolymers they are used in a new method known as polyjet. Out of two one photopolymer is a model material and another is support material. Support material is water soluble. The system has uV lamp which help in photo polymerizing. Surface texture of the path is very good since the layers are as small as 20 microns thick. Hence parts do not require any hand finishing. [16]

Table 2. Properties of the Materials used by Polyjet [19]

S No	Parameter Range	High temp materials	Rigid Materials	Soft Materials
1	Tensile Stength	70 – 80 MPa	50 – 65 MPa	0.8 – 1.5 MPa
2	Elongation	10 – 15 %	10 – 25 %	170 – 220 %

3	Impact Strength	14 – 16 J/m	20 – 30 J/m	NA
4	Shore Hardness	87 – 88	83 – 86	26 – 28
5	Distortion Temperature	75°c – 80°c	45°c – 50°c	NA
6	Polymerized Density	1.17 – 1.18 g/cm^3	1.17 – 1.18 g/cm^3	1.14 – 1.15 g/cm^3
7	Colour Options	NA	Transparent/Opaque	Black/Gray

~~6.~~5. APPLICATIONS

~~6.1.~~5.1. Ice as a support structure in photopolymerization processes

In traditional stereolithography process, overhanging portions are supported by the additional support material. Model material itself is used as a support material, but it is deposited sparsely. Different types of hollow structures are used for support. The problems with this type of support are –

•Valuable material is lost as a support structure which is not recyclable and disposed off once the model is ready

•It is time consuming for the user to manually remove all the support structures carefully from the model

•Removal of support structure may cause unexpected damage to the delicate features of the built objects.

•Surface finish is not achieved because the surface from where the support structure is removed leaves marks of the metal tools used for scraping off the support.

Photo. 2 Support being removed from a model with metallic tool (Courtesy - 3D Hub)

To overcome the above stated problems, a novel approach is used where support structure is made of water. The water support structure, i.e. ice, surrounds the build material after every layer.

A preliminary work related to this concept has been published by University of South California where ice is used as a support structure. The approach does not use a multi-jet technology, however, a specially designed deposition technique is used which is explained as follows[20] –

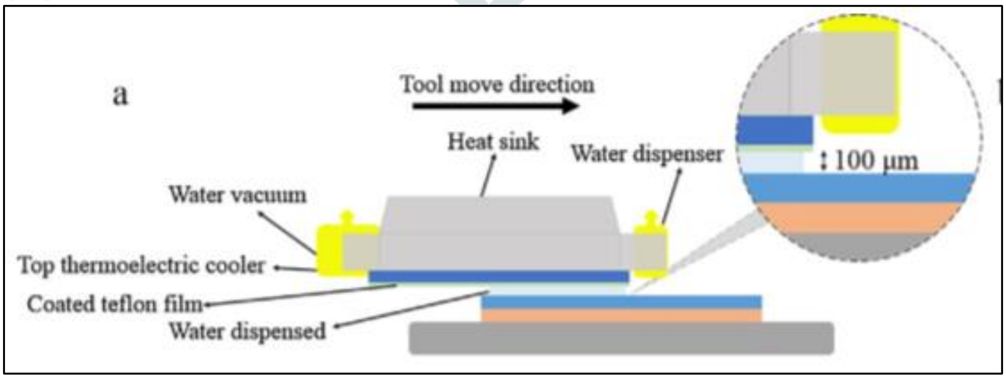

Fig. 17 Step - 1: Water is deposited on previous layer along with cooling by a thermoelectric cooler

In step 1, a complete layer of water is deposited on a surface. This makes the removal of the built part easy from the platform. Top thermoelectric cooler is coated with Teflon to make a contact with the water layer which freezes the water. After the water freezes into ice, the cooler moves away.

In subsequent layers, the water vacuum sucks the extra water on the layer after filling the cavities of the resin pattern deposited.

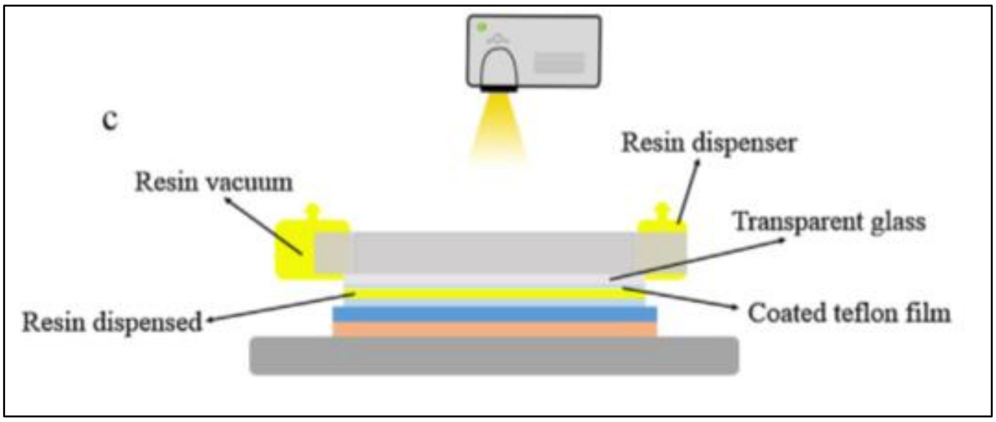

Fig. 18 Resin is dispensed above water and cured using UV light source

In step 2, the resin is dispersed through resin dispenser which deposits a complete layer of the resin on top of the ice surface. As soon as the resin is deposited, the UV light source on top flashes a pattern image which polymerizes the resin layer into the required pattern. When the tool moves away from the layer, the resin vacuum sucks the remaining resin in. It leaves the polymerized pattern on the top.

After that step 1 repeats where water is deposited in the cavities created between the resin patterns. The remaining water is sucked up by the water vacuum. The steps are repeated to get a layer-by-layer deposition and the part is completely printed.

One of the limitations with this process is that the volume expansion of the ice after solidification. One has to pre-calculate the expansion and then required amount of water has to be deposited and removed from the work surface to make the process more accurate. Another limitation is the complex system and process. The system involves two vacuums, both water deposition and resin deposition tools make contact with the previous layers, and there is a chance that water getting trapped between two layers of the resin which makes the resin-resin bond weaker and delamination of the part from between can take place. [20]

To counter these problems, a novel approach has been hypothesized at RM Lab , IIT Bombay. It involves using multi-jet nozzle system where materials can be precisely deposited in their locations. There can be two separate nozzle systems for ice as well as photopolymer. The multi-jet nozzle system is simple to use since there are no complex cooling systems or vacuums to be operated. Also, precise deposition can take place using inkjet systems.

6.2.5.2. Multi-jet Wax Modeling

There are various companies which fabricate wax 3D printers. Wax 3D printing has important application in investment casting based companies. The design driven industries like jewelry making, art industries and precision casting industries use wax 3D printing extensively.

Photo. 3 Jewelry by 3D printed patterns (Courtesy - Sterling Silver Co)

Currently, the quality printers are made by company called Solidscape which makes use of filament extrusion based technology of FDM. Although the accuracy and surface finish achieved by FDM are good, the process is very slow for printing intricate shapes where lot of support mechanism is required. Generally, wax with lower melting point is used as a support material which can be melted away to give the desired component. It uses a milling cutter which machines every layer after it is deposited to a fairly perfect horizontal surface where wax can further be deposited.

A company called Sculpteo used the technology of Multi-jet modeling for deposition of wax material with the help of piezoelectric jets. The support material used is the wax with lower melting temperature. It can help overcome the problem of using single jet wax deposition systems.

Another innovative idea being worked upon at RM Lab, IIT Bombay is the use of multi-jet technology to deposit wax just like sculpteo or solidscape. The major innovation goes into the selection of materials for deposition. The model material can used as photo-polymeric, resin, plastics, etc. The support material can be used as wax which melts at lower temperatures than the distortion temperatures of the most of the plastics used for 3D printing.

The advantage for using this type of technique is that, the precious model material is not wasted in the form of support which is later scraped off and disposed. Wax is cheaper than model materials. Another advantage with using wax is wax can be reclaimed after it is molten from the model. It also makes sure the surface texture remains smooth as there are no removal marks on the surface which are made in the process of scraping off the support structure. Use of multi-jet ensures the process being fast enough to complete bigger yet intricate parts.

~~6.3.~~5.3. Gas Multi-jet Printing

Gas printing is an emerging idea based on the recent experiments carried out in the Sand section of the Rapid Manufacturing Lab at IIT Bombay. There are currently no systems available for printing of gas. Also, this is an area which is still unexplored by the researchers in the field of 3D printing.

The rationale behind gas 3D printing is that in this date, the material can be printed only in two states, either in solid (by extrusion) or by liquid (inkjet printing followed by evaporation). There can be possibility of using gas as a deposition material where there is suitable application where the gas is required to be deposited precisely in a pattern. Such an application is in our hand.

The gas printing is required for the sand bed 3D printers where sand is used as model material. The silica sand is mixed with sodium silicate which is a hardener. The mixture of silica sand and sodium silicate is used as a model material. The powder spreading mechanism spreads the mixture as a layer. With the help of a multi-jet nozzle system or its equivalent can deposit the CO_2 gas which reacts which sodium silicate and forms silica gel, which creates bonding between silica particles. [21]

$$Na_2\,Si_2\,O_5\,.H_20\,(l) + CO_2\,(g) = Na_2CO_3.\,H_20 + SiO_2\,(gel)$$

Above reaction explains the chemistry that takes place when CO_2 is reacted with Silica Sand and Sodium Silicate Mixture.

~~7.~~6. CONCLUSION AND FUTURE SCOPE

In this paper, the significance of inkjet/multi-jet technology in the fields of 3D printing has been highlighted. The available technology of inkjet/multi-jet, their advantages and limitations are of importance since this study opens up doors to the potential innovation that can be brought about.

As discussed in the paper, the global players like Stratasys, 3D Systems, Sculpteo, etc. are the evidence of commercial success of the process of multi-jet 3D printing. There are many other Asian and Overseas companies which are bringing in innovation at their own levels. Research of multi-jet technology in terms of machine design, materials, and control systems proves to be very relevant in current times.

From this review, the gaps in current multi-jet technology can be enlisted which can gives us a scope for further research –

- Printing with novel materials like water, sand, etc. is an unexplored area which has a phenomenal potential as a technology. Currently, there are very less commercial 3D printer available in the market for such products.Mostly they use single jet technique. Thus, multi-jet printhead can be explored for faster process with good surface properties.
- The wax 3D printers which are based on MJM like Sculpteo, Soliscape are very expensive. The small and medium scale foundries in Indian markets predominantly use extrusion based printers where wax filaments are used. Indigenization of the multi-jet technology has a potential to open up new segment in the wax based 3D printers in India.
- Almost all printers except PolyJet use single material for model making. Use of inexpensive, easily available materials like water can be used in tandem with traditional photopolymeric materials which can eliminate the need of using costly model materials as support materials in the light-based 3D printer

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