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Competency of 4D Printing in Additive Manufacturing

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ABSTRACT

Additive manufacturing use to construct a three dimensional object from a computer aided design model, generally by successively adding material layer on layer 3D printing were appropriate for the production of practical prototypes and a more acceptable name for it was given prototyping. Although enormous amount of research has been made in this field, there is still a lot of research work to be required in order to overcome the various challenges remained. In 2019, the repeatability, precision, and material range have increase to the level that some 3D printing processes are accepted as an industrial-production technology, the term additive manufacturing can be used with 3D printing. One of the big advantages of 3D printing is to make very complex shapes, including parts with hollow parts to reduce weight, and producing any 3D printed part is a 3D model. However, 4D printing adds the dimension of restoration or change over time. It is therefore a type of programmable matter, where in after the fabrication process, the printed product reacts with parameters within the environment (i.e. humidity, temperature, wind, water, etc. and changes its form accordingly.Smart materials are those materials that have the ability to change their shape or properties under the effect of external encouragement. With the introduction of smart materials, the most 4D printing systems utilize a network of fibers that vary in size and material properties and such components are able to alter their shape or properties over time as a response to the applied external change. Therefore, this gives stand up to a new term called 4D printing to include the structural restructuring over time. In this paper, we compare 3D and 4D printing process, recap basics of 4D printing processes including materials that use for 4D printing and find its application strength in different fields, so finally able to explore the competency of 4D printing processes and challenges, applications, research directions and future trends of 4Dprinting.

Keywords: Additive Manufacturing(AM),Shape memory polymer (SMP), Fibber architecture, Liquid Crystalline Elastomers

1. INTRODUCTION

More than three decades in additive manufacturing 3D printing playing important role in improving long term solutions, efficiency, cost reduction to remodel manufacturing field . By involvement of 3D printing work in an industry becomes easier as now producing a component does not require different set of machinery, tools and equipment. For making a product through 3D printing require 3D printable models may be created with a CAD package, by a 3D scanner, 3D printed models created with CAD result in minimize errors and can be corrected before printing, allowing verification in the design of the object before it is printed Printing of any type of shape (from simple to complex) gave an additional advantage in manufacturing as one was able to see the part in final form and all pros and cons could be tested at the same time new innovations can be expected in the current models. Evolution of internet of things| gave a sharp edge to additive manufacturing so due to this cost and time in printing reduced. There is wide variety of part materials like plastics, resins, metals, polymers, bio degradable, food material etc.

The production capability of 3D printing process of such materials is continuously increasing and with the introduction of smart materials, the most 4D printing systems utilize a network of fibers that vary in size and material properties and such components are able to alter their shape or properties over time as a response to the applied external change. Hence, this is also develop new term called '4D printing' to include the structural restructuring over time.

2. LITERATURE REVIEW

We are familiar with laser or inkjet printer those days that prints photographs and documents. Texts and images are printed by placing and controlling ink or toner on the surface of paper. In similar way, 3D printers prints objects by controlling the position and adhesion of specimen in 3D space. It is an additive manufacturing process, where materials are added precisely unlike subtractive process where materials are removed to get final object.

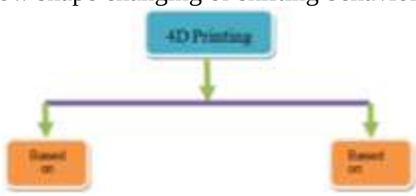
In 3D printing of an object, digital model of specimen is required in the computer. 3D model can be designed using Solid works, computer aided design, or other different modeling softwares. Also, 3D scanner can be used to scan a model and convert it into digital data. Furthermore, slicing software is needed in order to slice up the model into many cross sectional layers and finally to be sent to 3D printer where model is printed layer by layer forming a complete 3D printed object. But as the advanced and rapid development in printing technology has taken itself to next level, 3D printing has allowed the printing of smart materials designed to change shape and function, so called 4D printing technology. With a great potential to transform everything from our daily lives, it has become disruptive technology for future advanced manufacturing systems.

Skylar Tibbits -2013 in collaborations with Stratasys developed a long strand that folded into letter Masschuate institute of technology (MIT)‖ and complex self-folding Hilbert curves when dipped in a water tank. In first experimented they printed structure as a single strand containing both rigid and active materials. While in second experiment the strand was longer than first experiment but with the difference that at each of the joints two rigid discs was printed .These discs worked as angle limiter when folding and touching on another face. This limited the maximum angle at 90 degrees.

Yamagishi et al., 2013 created 3D printed figure (gel matrix) of transfer tissues and showed the geometric change for different types of patterns such as sphere 1 and 2, Ellipse, Y shaped structure 1 and 2 for different problems (Figure 3) .In this work Yamagishi et al., 2013 concluded that high circularity of transfer tissues demonstrated excellent transcriptional behavior by successful assembling of these three dimension tissues into tubular construct.

3. TYPES OF 4D PRINTING

4D printed parts can be created by various 3D printing processes based on the suitability and capability of 3D printing machine and availability of material. However the approaches for making a 4D printed product can be classified as design based 4D printing and material based 4D printing. The first one comprises the efforts applied in the design so on the exposure to stimuli the shape shows some controlled dynamic behavior while in second approach uses materials which show shape changing or shifting behavior.



4. MATERIALS USED

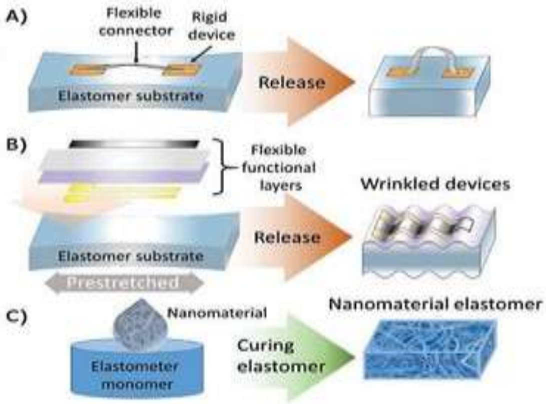
Main motivation using 4D printing is that it is providing a vast platform for researchers to make a utility object with desired dynamics when exposed to certain environment. This dynamics is based on the capability of the smart material and its compatibility with printing method.4D printing with suitable materials leads to saving of space, cost, inclusion of minimum number of movable parts into to where they can think about making savings in space, cost, minimum number of movable parts as the final product is going to take a very less space as compared to other conventional fabricated product and when take final shape when desired stimuli provided. The materials for 4D printing may be shape memory polymers (SMPs); shape memory alloys (SMAs); soft gels and composite active materials with different shape memory effects. All smart materials have different materials properties and quality of degrading itself with time. These two things decide the application and its printing method. Research on materials used in 4D printing has very bright future.

4.1 Fibber architecture

Many 4D printing structure make use of a network of fibres that differ in size and material properties 4D printed elements can be designed on the macro scale as well as the micro scale. Micro scale design is get through complex fibre simulations that approch the aggregated material properties of all the materials used in the sample. The size, shape, modulus pattern of these material building blocks has a direct relationship with the deformation shape under excitant activation.

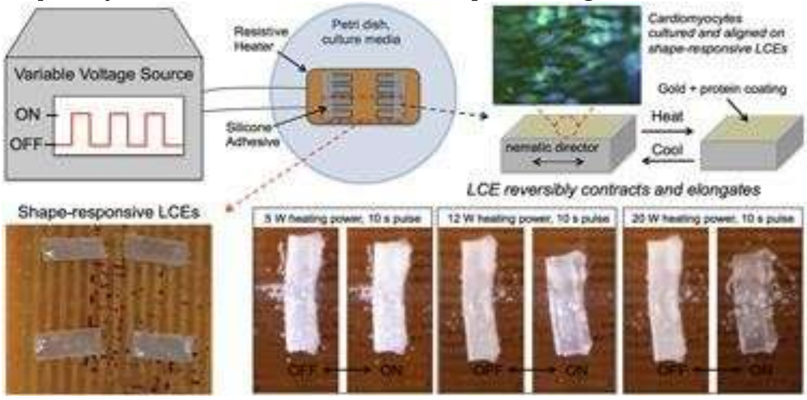
4.2 Digital Shape Memory Polymer

Digital shape memory polymers are capable to recover their original shape from a distorted shape under certain conditions, such as when exposed to a temperature for a period of time depending upon the polymer, there may be different configurations that the material lay hold of a number of temperature conditions. Digital SMPS utilize 3D-printing technology to precisely engineer the placement, geometry, and mixing and curing ratios of SMPS with differing properties, such as glass transition or crystal-met transition temperatures. In this technique a series of digital SMP hinges that have Different prescribed thermo- mechanical and shape memory behaviors, which are grafted onto rigid, on-active materials. Thus develop a self folding sample that could fold without interfering with itself and even interlock to create a more robust structure.



4.3 Liquid Crystalline Elastomers

LCE are a class of soft active materials which can achieve rapid and reversible shape changes. This is in contrast to SMPs which typically require a programming step and thus the actuation is generally one time and non reversible. Hydro gels on the other hand can yield large and reversible volume change, however their response speed is relatively slow.LCE achieve their actuation through a transition of the molecular chains between an ordered liquid crystal state and a random stat in response to light,heat,electrical or magnetic field.



4.4 Multi Material 4D printing Using LCEs

The concept of utilizing multi-material 4D printing using LCE to create reversible actuation of complicated structures here, a three layer hinge was created by placing prefabricated LCE on a 3D printed silver wire and elastomer structure Joule heating was then used to heat the LCE past its transition temperature ((TNI) The basic hinge design is entirely 3D printed and utilized to create structures that could achieve complex folding and activation sequences. Among other demonstrations, a hand was 3D printed such that each finger could be activated separately to produce letters from the American Sign Language alphabet.

5. COMPETENCY OF 4D PRINTING IN VARIOUS APPLICATIONS:

5.1 Architecture

Common adaptive frontages and opening roofs require complex mechanical systems to operate which are often difficult to install and frequently malfunction 4D printed frontages would offer simplicity of installation and direct instigation happened by climate conditions eliminating any need for a larger controlling system or input energy.

5.2 Biomedical

4D-printable, photo-curable liquid resin is made of a renewable soybean-oil epoxidized acrylate compound that is also biocompatible. This resin adds to the small group of 3p. printable resins and is one of the few that are biocompatible A laser 3D-printed sample of this resin was subjected to temperature fluctuations from -18 "C to 37°C and exhibited full recovery of its original shape Printed skeletons of this material proved to be successful foundations for human bone marrow mesenchymal stem cell (HMSCS) growth This material's strong qualities of shape memory effect and biocompatibility lead researchers to believe that it will strongly advance the development of biomedical frameworks. The use of plant oil polymers as liquid resins for stereolithography production in biomedical applications.

5.3 Cell Traction Force

Cell Traction Force (CTF) is a technique wherein living cells fold and move microstructures their designed shape. This is possible through the contraction that from acting (multifunctional proteins) polymerization and actomyosin (group of muscle cells) natural into occurs interactions within the cell. In processes, CTF regulates wound healing, angiogenesis, metastasis, and inflammation seeding of cells across two micro plates, and when the glass structure was removed the cells would bridge the gap across the microplate and thus initiate self-folding

5.4 Electrical and Magnetic Smart Materials

The electrical accessible materials that exist today change their size and shape depending on the intensity and/or direction of an external electric field. Polyaniline, polypyrrole etc. are good conducting materials and can be doped with tetrafluoroborate to contract and expand under an electric stimulus. A robot made of these materials was made to move using an electric pulse of 3V for 5 seconds, causing one leg to extend, then removing the stimulus for 10 seconds, causing the other leg to move advance. Research on carbon nanotubes, which are biocompatible and highly conductive, indicates that a composite made of carbon nanotube and a shape memory specimen has a higher electrical conductivity and speed of electro-active response than either specimen alone. Magnetically responsive material contract in the presence of a strong magnetic field and thus has applications in drug and cell delivery. The combination of carbon nanotubes and magnetically responsive particles has been bioprinted for use in promoting cell growth and adhesion, while still maintaining a strong conductivity

5.5 Commerce and transportation

Future applications of 4D-printed materials as programmable products that can be tailored to Specific environments and respond to factors such as the temperature, humidity, pressure, and Sound of one's body or environment Some study also mentions the advantage of 4D-printing for shipping applications it will allow products to be packaged flat to later have their designed shape activated on site by a simple stimulus. There is also the possibility of 4D-printed shipping containers that react to forces in transit to uniformly distribute loads.These materials will be able to self disassemble, making their constituent parts easy to recycle.

6. CONCLUSION

Acceptability of environment and usefulness to manufacture at low cost, minimum number of moving components and minimum production time are the basic requirements of any process to be selected with smart materials. On the basis of end use its basic functions are decided. In the present paper so far we have discussed on the basic concepts of 4D printing, materials for 4D printing, printing types of 4D printing and applications of 4D printing. Exploring possible uses of stimuli responsive materials are already interest of researches but inclusion 3D printing making this research very emerging trend. There is no doubt that with SMPs, demands of modifications in existing 3D printers are increased to make it compatible up to an extent. The popular and most viably applied 4D printing methods in Additive Manufacturing(AM)with selected Shape memory polymer (SMP), Fibber architecture, Liquid Crystalline Elastomers.In this paper written various industrial applications of 4D printing chalked out practically. 4D printing has the capability to print an object responsive to external environment in a better way than the conventional methods.

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