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Mini Review

4D Printing -Will it be a Game-Changer?

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Abstract

The 3D printing is a well-known technology across the world and this is actually changing the manufacturing machining concept as well as opens up the possibility of products based on consumers design. The economy and market strategy of the manufacturing sector is on the verge of total remodelling. Within the shadow of 3D printing technology, 4D printing is also gaining interest since it has reversible self-shape transformation capability which mimics biological growth process. This has also a huge implication for tissue engineering and space programs. Here a glimpse of 4D printing technology has been given with a touch of materials like shape memory polymer and hydrogel which are used frequently for 4D technology.

Keywords: 3D printing; Shape memory polymer; Hydrogel

Introduction

Specific geometrical shapes of substances are required for almost every object. The structure of the substance helps it to fulfill a certain set of actions. A simple work could be done by a simple shape or structure but a complex job may need multifaceted structure/s. In one word, the structure of the substance is a useful aspect of the job it is assigned. The functions of the sophisticated devices like in biomedical and aerospace are limited by its precise structure and vice-versa.

Traditional processing of different structuring follows till the medieval technology of molding-demolding. This technique is crippled for its dilatory speed of construction, difficulty, cost of creating complex molds, and wastages from demoldings. Additive manufacturing which is also known as 3D printing is enthralling as a budding technique for complex shape production. In 3D printing, the structure is build up by laying consecutive layer, and the layers, are formed by scan lines. However, this 3D printing is amazing in sense that it is possible to fabricate any type of shapes, no matter how complex is the design starting from the biomimetic object or advanced engineering concept. But the bottlenecks of extensive utilization of this technique are size constraints, limitation of the materials to be used, integration of between them, and the stepwise formation process which restricts processing speed [1]. With every new technology, it takes some time to harness the full benefits out of it -this is the optimization time. Similarly, the 3D printing technology is in its maturing state. Machinery and resolution of the printing process are being improved; new materials are being developed and aimed; and continuous manufacturing processes instead of step-wise fabrication are being applied to overcome the slow-speed processing.

Self-assembling structures or structurally programmed substances are emerging and find their increasing utilization with the advent of robotics, photovoltaics, antennas, inertial measurement units etc. Structures with the capability of reversible change in shapes or programmed shape changes are fascinating as they have immense applicability in the fields of soft robotics, implantable medical devices, and customized consumer products [2]. The technology in which the printed structures evolved in shapes with time is known as 4D printing. The name "4D" comes since an extra dimension i.e. time is involved in this printing technique. In 4D printing, the material is printed in 2D instead of 3D; upon triggering right stimuli the material morphs itself to a predetermined 3D shape. The flat printing also enables to assemble diverse materials simultaneously. In electronics, where solvent-based ink has to be printed and finally a 3D morphed structure is expected, there 4D printing comes out handy due to the fact that it can exclude the risk of droplet spreading and non-uniform thickness. Then various origami- and kirigami- inspired mechanisms are utilized which direct to the final predetermined shape of the structure. The complex structures may evolve several orders in magnitude of length scale through controlled buckling, pneumatical transformation, controlled creasing, photo-induced folding, stress-induced curling, thermal controlled swelling, and use of shape-memory composites etc. [3].

From materials' point of view, several material strategies should be formulated for 4D printing. The main aspect of these materials should be programmable to manipulate macroscopic shape selection. Currently, shape memory polymers are able to mechanically transit between printed shape and a predetermined shape in response to external stimuli. Shape memory polymers can change shapes various with different stimuli like heat, light, ultrasound, and chemicals etc. Zarek et al. [4] printed a photocurable polymer with dual shape memory effect based on polycaprolactone and isocyanatoethyl methacrylate via an alcohol–isocyanate reaction. Recently, Xie et al. [5] printed a shape memory polymer by light curing process, which evolves in 3D structure when immersed in water. There are several other examples can be mentioned. Though more than one shape memory polymers can be utilized for complex and sequential structure morphing but tunable shape memory polymers have the possibility of highly complex and multi-sequential structure in a pre-programmed way [6]. There are very few examples of such tunable shape memory material as they are rare (Figure 1).

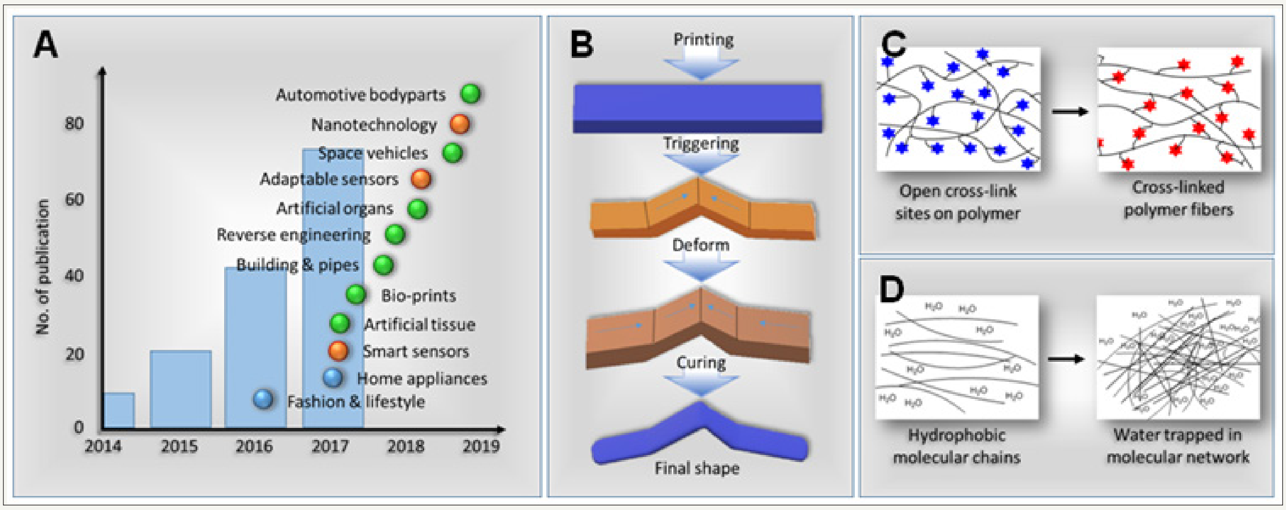

Figure 1:
1a: The year-wise number of publication of 4D printing related articles in scientific journals. The almost bi-fold increasing rate of publications in each year shows growing interest in the field. The timeline of 4D printing technology would be realized in different applications is also overlaid. Blue balls, green balls and orange balls indicate everyday consumer sector, health and machinery sector and electronic sector respectively.
1b: The typical 4D printing process. This involves four steps: printing of the substance (as flat print), then triggering the stimulation and deformation of the substance takes place, unloading the stimulation and curing the shape to finalize.
1c: Generalized shape memory polymer working principle. The stars indicate the cross-linking sites on polymer fibers; blue and red ones are for open and occupied sites respectively. After the stimulation, the cross-linking among the fibers materializes which maintains the gap between the fibers and thus keeps the shape of the substance.
1d: Representative schematic for hydrogels. The hydrophobic molecules form networks by cross-linking which can trap water molecules for swelling of the substance.

Another interesting group of materials used for the 4D printing is hydrogels. The hydrogels are generally 3D networks of polymer chains formed by crosslinking. This cross-link process may either be temporary or permanent by forming physical contacts or covalent bonds. However, these networks swelled by uptaking water molecules which get trapped inside the networks gaps. Due to the water-based working environment, the hydrogels are biocompatible and useful for biological applications. The swelling property makes them a smart candidate for 4D printing. This property can be controlled by crosslinking site density, surface modification, and size of the hydrogel particles. Raviv et al. [7] prepared a hydrogel mixing vinyl caprolactam, polyethylene and diacrylate oligomer which can expand almost 200% under water. Gladman et al. [8] synthesized a composite hydrogel with cellulose fibrils in acrylamide matrix which mimics plant cell wall structure. However, printing and lithographic processes often lack control over cross-linking site density which refers un uniformed response to applied stimuli [9].

Though there is a growing interest in 4D printing, still some issues have to be clarified. The stimuli-responsive material has to be printed pixel-after-pixel for better functioning of that under excitation-which inherently limits its speed though the process can skip multilayer build-up in the Z direction. There is less availability of good self-shape transforming materials which gives limited options to experiment. Again some of the stimuli for the substances may not useful for some specific types of applications. That also tills an obstacle for widespread utilization of this promising technology.

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References

1. Huang L, Jiang R, Wu J, Song J, Bai H, et al. (2017) Ultrafast digital printing toward 4D shape changing materials. Advanced Materials 29(7): 1605390.
2. Ambulo CP, Burroughs JJ, Boothby JM, Kim H, Shankar MR, et al. (2017) Four-dimensional printing of liquid crystal elastomers. ACS Applied Materials & Interfaces 9(42): 37332-37339.
3. Sundaram S, Kim DS, Baldo MA, Hayward RC, Matusik W (2017) 3D-printed self-folding electronics. ACS Appl Mater Interfaces 9(37): 32290-32298.

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4. Zarek M, Mansour N, Shapira S, Cohn D (2017) Macromolecular rapid communications 38(2): 1600628.

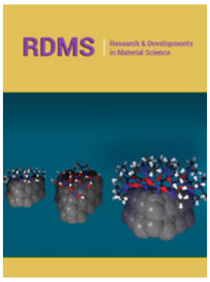
5. Xie T, Tunable (2010) Polymer multi-shape memory effect. Nature 464(7286): 267-270.

6. Chen S, Zhang Q, Feng J (2017) 3D printing of tunable shape memory polymer blends. Journal of Materials Chemistry C 5(33): 8361-8365.

7. Raviv D, Zhao W, McKnelly C, Papadopoulou A, Kadambi A, et al. (2014) Active printed materials for complex self-evolving deformations. Scientific Reports 4: 7422.

8. Gladman SA, Matsumoto EA, Nuzzo RG, Mahadevan L, Lewis JA (2016) Biomimetic 4D printing. Nature Materials 15: 413-418.

9. Xue B, Kozlovskaya V, Kharlampieva E (2017) Shaped stimuli-responsive hydrogel particles: syntheses, properties and biological responses. Journal of Materials Chemistry B 5(1): 9-35.



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