Mini Review

The Next Generation of Smart Structures with Embedded Sensor Capabilities

Dionysios E Mouzakis*

Laboratory of Mechanics, Hellenic Army Academy, Greece

*Corresponding author: Dionysios E Mouzakis, Laboratory of Mechanics, Hellenic Arme Academy, Greece

Abstract

In the first and second decades of the 21st century nanotechnology has given impetus to a new generation of materials namely smart materials. Having the abilities to transform in shape, to sense and correspond to external stimuli like temperature, pressure, sound, etc. and to counteract these, they excited the engineers into many new concepts like adaptive structures in aeronautics, active biomaterials and smart self-healing composite materials. This scheme was corroborated by the parallel progress in nanotechnology, as well as a real explosion in the additive manufacturing technologies, which enabled many types of sensors and smart or responsive nanomaterials to be incorporated into structural parts. This mini review paper provides an opinion on these new conceptual technologies such as 4D printing into the oncoming third decade of the century which has already been characterized as the era of nano - and bio- engineering.

Introduction

The beginning of the 21st century provided many interesting features in engineering. To begin with, the technology of high performance fiber reinforced composite materials, especially carbon fiber reinforced thermosets, reached their peak in maturity [1], thus commercial passenger aircraft such as the Boeing 787 and the Airbus A350 series are nowadays manufactured with a dead weight of more than 50wt% in high performance composites, attaining fuel economies of 20 or more percent [2]. The eve of nanotechnology provided further impetus to research with carbon based single and multiwall nanotubes [3] and other types of nanofibers [4] as further potential reinforcements but with no impressive results as yet. Also, since the discovery of graphene [5,6], new aspirations for materials with exotic properties were driving multibillion research worldwide but no real structural application has seen the light too.

However, all the extremely intensive research in nanocomposites and nanomaterials, with journal papers numbering already 130k Journal Papers in 2011 [7], and more than 166k in 2018 [8], provided researchers and engineers with a new perspective for materials which were named "smart" and /or "adaptive". These materials either manufactured by nanotechnology methodologies as adaptive or sensing per se [9] or being reinforced with nano-structured stimuli responsive fillers [10] are nowadays supposed to provide the structures or structural parts of the coming decades with smart and adaptive features. Moreover, the last ten years saw an avalanche in the sector of additive manufacturing technologies (or 3D printing in the popular media) of all levels and in many commercial and industrial applications [11]. This led the researchers to focus their attention again on exploiting such technologies combining them with existing knowledge gained in the past twenty years on sensory and adaptive/smart materials to create a new category namely the 4D printed materials [12]. This short review provides an insight into the latest progress achieved in smart materials, sensors and structures and also the new 4D smart printed parts family in advanced applications such as Nanomedicine [13].

Examples of the Recently Developed Smart and Responsive Structures

Recently, some interesting applications of smart and adaptive materials and structures emerged in the light of literature. An ultrahigh resolution pressure sensor based on percolative metal nanoparticle arrays was developed in Hubei and Nanjing Universities, China [14], with the ability to provide sensitivity of 0.13kPa−1, which corresponds to ca. 1m of barometric altitude resolution. C. Varnava published two articles on nanowire-

networks and flexible photodetectors which can evolve quickly into products including smart windows, foldable screens and wearable electronics [15], and another on the importance of MEMS sensors in the flight control circuits for unmanned air vehicles for civilian as well as military purposes [16]. Carbon Nanotube (CNT) yarns have been assessed for many uses including flexible electronic sensors and electrodes to measure strain, temperature, ionic concentration, and concentrations of certain monitored biomolecules. In twisted form CNT yarn exhibit strong torsional actuation, and when coiled CNT yarns generate large tensile strokes hinting for a future use as artificial muscle. Next-generation of energy storage and harvesting systems can be also based on CNT's superconductive-supercapacitative electrical behavior [17]. The integration of sensors into structures with additive manufacturing is not always straightforward and is pointed out by many researchers [18] which argue that new horizons are opened but also challenges are there too considering the additive manufacturing methodologies. On the other hand, stimuli responsive materials are nowadays widely named as 4D printed materials since 2013, described as 3D printing of multifunctional materials [19]. Especially in the field of biotechnology, 4D printed scaffolds for tissue engineering [20] and biomedical devices e.g. rapid virii detection microdevices [21] are being suggested as possible applications. The wide availability in cheap lab-scale FFF (fused filament fabrication) or FDM (fused deposition modeling) 3D printers has led also many researchers to incorporate small particles in filaments and/or graphene and print novel 4D hybrid materials [22]. Needless to mention also fluid inks with graphene have been also proposed for cell scaffolds and molecular arrays in biosensing applications [23]. It is anticipated that the complex procedures in human tissue regeneration and healing offers a whole new field of application for 4D printed scaffolds [24]. It appears that biotechnology now benefits from both the innovation of rapid manufacturing as well as the tremendous steps in nanotechnology in the previous two decades [25].

Conclusion/Opinion

It is always not easy to foresee the future of course. As mentioned above there is a strong driving force however, for 4D printed or smart adaptive structures based on several types of polymers, most of them enabled for 3D printing, or additive manufacturing. The revolution in nanotechnology has proved smart nanoparticles and nano-arrays with extreme sensing capabilities and researchers are trying mostly to incorporate them in smarter and more efficient structures such as scaffolds for tissue engineering, bio-devices for drug delivery and immune-sensing or other like photo–electronic circuits and devices. The future trends are also pointing in the direction of energy storage and harvesting also.

Acknowledgements

References

1. Charles E Harris, James H Starnes, Mark J Shuart (2002) Design and Manufacturing of Aerospace Composite Structures, State-of-the-Art Assessment. Journal of Aircraft 39(4): 545-560.

2. Mrazova, Maria (2013) Innovations, technology and efficiency shaping the aerospace environment. INCAS Bulletin 5(2): 91-99.

3. Ayesha Kausar, Irum Rafique, Bakhtiar Muhammad (2016) Review of Applications of Polymer/Carbon Nanotubes and Epoxy/CNT Composites. Polymer-Plastics Technology and Engineering 55(11): 1167-1191.

4. Jiang S, Chen Y, Duan G, Mei C, Greiner A, et al. (2018) Electrospun nanofiber reinforced composites: a Review. Polymer Chemistry 9(20): 2685-2720.

5. Young RJ, Kinloch IA, Gong L, Novoselov KS (2012) The mechanics of graphene nanocomposites: A review. Composites Science and Technology 72(12): 1459-1476.

6. Lawal, Abdulazeez T (2019) Graphene-based nano composites and their applications. A review. Biosensors and Bioelectronics 141: 111384.

7. D de la Iglesia, Diana Cachau, Raul, Garcia-Remesal, Maojo V (2013) Nanoinformatics knowledge infrastructures: Bringing efficient information management to nanomedical research. Comput Sci Disc 6(1): 14011.

8. Statnano: Newsroom-Nanotechnology Publications of (2018): An Overview.

9. Ma Xiaodan (2019) Hybrid superhydrophilic-superhydrophobic micro/nanostructures fabricated by femtosecond laser-induced forward transfer for sub-femtomolar Raman detection. Microsystems & Nanoengineering 5(1): 1-10.

10. Koduru JR, Karri RR, Mubarak NM (2019) Smart Materials, Magnetic Graphene Oxide-Based Nanocomposites for Sustainable Water Purification. Sustainable Polymer Composites and Nanocomposites. Springer 759-781.

11. Mouzakis DE (2018) Advanced Technologies in Manufacturing 3D-Layered Structures for Defense and Aerospace. In Lamination-Theory and Application.

12. Kuang X, Roach DJ, Wu J, Hamel CM, Ding Z, et al. (2018) Advances in 4D Printing: Materials and Applications. Adv Funct Mater 29(2): 1805290.

13. Wei Zhu, Thomas J Webster, Lijie G Zhang (2019) 4D printing smart biosystems for nanomedicine. Nanomedicine 14(13): 1643-1645.

14. Minrui Chen, Weifeng Luo, Zhongqi Xu, Xueping Zhang, Bo Xie, et al. (2019) An ultrahigh resolution pressure sensor based on percolative metal nanoparticle arrays. Nature Communications 10(1): 4024.

15. Varnava Christiana (2018) Nanowire networks crack on. Nature Electronics 1(6): 326.

16. Varnava Christiana (2019) MEMS sensor in flight control. Nature Electronics 2(8): 322-322.

17. Jang Y, Kim SM, Spinks GM, Kim SJ (2019) Carbon Nanotube Yarn for Fiber-Shaped Electrical Sensors, Actuators, and Energy Storage for Smart Systems. Adv Mater 1902670.

18. Dijkshoorn A, Werkman P, Welleweerd M, Wolterink G, Eijking B, et al. (2018) Embedded sensing: integrating sensors in 3-D printed structures. J Sens Sens Syst 7: 169–181.

19. Kuang X, Roach DJ, Wu J, Hamel CM, Ding Z, et al. (2018) Advances in 4D Printing: Materials and Application. Adv Funct Mater 29(2): 1805290.

20. Zhu W, Thomas J Webster, Lijie G Zhang (2019) 4D printing smart biosystems for nanomedicine. Nanomedicine 14(13): 1643-1645.

21. Jacky FC Loo, Aaron HP Ho, Anthony PF Turner, Wing Cheung Mak C (2019) Integrated printed microfluidic biosensors. Trends in biotechnology 37(10): 1104-112.

22. Sharma R, Singh R, Batish A (2019) Study on barium titanate and graphene reinforced PVDF matrix for 4D applications. Journal of Thermoplastic Composite Materials 0892705719865004.

23. Vlăsceanu GM, Iovu H, Ioniță M (2019) Graphene inks for the 3D printing of cell culture scaffolds and related molecular arrays. Composites Part B: Engineering 162: 712-723.

24. Lui YS, Sow WT, Tan LP, Wu Y, Lai Y, et al. (2019) 4D printing and stimuli-responsive materials in biomedical aspects. Acta biomaterialia 92: 19-36.

25. Koons GL, Mikos AG (2019) Progress in three-dimensional printing with growth factors. Journal of controlled release 295: 50-59.

To Submit Your Article Click Here: [Submit Article]

JOMME

Journal of Mining & Mechanical Engineering

Journal Of Mining And Mechanical Engineering

Assets of Publishing with us

- Global archiving of articles
- Immediate, unrestricted online access
- Rigorous Peer Review Process
- Authors Retain Copyrights
- Unique DOI for all articles