Transactions on Engineering and Technology Research
ISSN: 2960-1797, eISSN: 2960-2246 | Volume 4
ACEGE 2024

Research on Intelligent Materials in the Civil Engineering Field

Yaqi Huang*

International College of Engineering, Changsha University of Science & Technology, Changsha, China

* Corresponding Author: 202227010212@stu.csust.edu.cn

Abstract. With the continuous development of civil engineering technology, the requirements for material properties are getting higher and higher, and intelligent materials have attracted much attention as a new field. Based on the background of civil engineering, this paper discusses the research progress of four intelligent materials: carbon fiber concrete, nano carbon black concrete, shape memory alloy (SMA)and piezoelectric materials. The performance characteristics, application advantages and shortcomings of these four materials in civil engineering are mainly studied. Through comparative analysis, the excellent properties of carbon fiber concrete in terms of strength and durability, the significant improvement of mechanical properties and electrical conductivity of nano carbon black concrete, the unique advantages of SMA in earthquake self-healing, and the important role of piezoelectric materials in structural health monitoring are revealed. The conclusion shows that although intelligent materials show great potential in performance, problems such as cost, process and performance stability remain to be solved. The research in this paper not only enriches the research system of civil engineering materials, but also provides theoretical reference and practical guidance for the wide application of intelligent materials in civil engineering in the future.

Keywords: Intelligent materials; Intelligent concrete; Shape Memory Alloy; Piezoelectric Materials.

1. Introduction

The harsh and intricate environmental conditions pose significant challenges in civil engineering construction. Intelligent materials can effectively make up for the lack of old materials, and adapt to the internal and external environment in a more complex environment, so as to improve the construction efficiency of civil engineering and the stability of buildings. Intelligent material is a new type of material that can react to changes in the external environment and perform tasks on its own. Therefore, the research of intelligent materials is of great significance in the field of civil engineering.

The concept of intelligent materials was first proposed by the United States in the 1990s, and it is the fourth generation of materials after natural materials, synthetic polymer materials, and artificially designed materials [1]. It is mainly divided into two types, one is the perception material, which can sense the intensity of various internal or external stimuli, including light, electricity, heat, radiation, sound and chemistry. This kind of materials mainly consists of sensing material, shape memory alloy (SMA), piezoelectric film and optical fiber. The second type is the driving material, which can give early warning and react and drive when the internal state and external environmental conditions change, such as the common piezoelectric ceramics, magnetic flux variant and electric current variant [2].

As a new type of material, intelligent materials mainly have the functions of imitation, sensing, self-diagnosis, repair and adjustment. As the name suggests, intelligent materials build adaptive systems by mimicking the structure, function, and principles of living organisms. Examples include high-strength materials that mimic seashells and super-tough fibers like spider silk. The sensing function is that the intelligent material forms a central system similar to the CPU based on its own molecular properties, so as to identify the internal and external environment and achieve the purpose of self-regulation and self-adaptation. In terms of self-diagnosis, repair and adjustment capabilities, intelligent materials can self-monitor and diagnose their internal performance and external changes, detect reports in time, automatically start the repair mechanism when damaged, and restore their

Content from this work may be used under the terms of CC BY-NC 4.0 licence (https://creativecommons.org/licenses/by-nc/4.0/).
Published by Warwick Evans Publishing.

original performance and function. In addition, the material can automatically adjust its performance parameters and response mode according to changes in environmental conditions to adapt to different application scenarios [1-3].

In this paper, the performance characteristics and applications of four intelligent materials, carbon fiber concrete, nano carbon black concrete, SAM and piezoelectric materials, are systematically analyzed, and then the limitations and future prospects of intelligent materials in civil engineering are discussed.

2. The Application of Intelligent Materials in Civil Engineering

2.1. Carbon Fiber Reinforced Concrete (CFRC)

CFRC material refers to the addition of carbon fiber to concrete to improve and enhance the performance of concrete. As an efficient reinforcement material, carbon fiber has a carbon content of up to 92-100% and a density of 1.75g/cm^3 [3, 4]. This material has the characteristics of high strength, high elasticity, fatigue resistance and strong electrical conductivity, which greatly enhances the toughness of concrete. Their special electrical conductivity and significant length-to-diameter ratio make it easier to form conductive networks in cement. In 1989, the team of Hung in the United States first found that adding short carbon fiber to cement concrete can make the material have self-sensing characteristics [5]. This kind of composite material can see the internal condition of the resistance under different working conditions through the resistance change rate. Because the resistance of carbon fiber concrete is related to stress and strain, the stress condition of concrete can be directly reflected after the resistance receiver is connected to the computer, thus realizing real-time monitoring of its working state [5]. At present, this technology has been applied in some sections of cofferdam of the Three Gorges Project of Yangtze River in China, and good results have been achieved.

At the same time, CFRC also has good temperature sensitivity. Because of its material properties, carbon fiber will produce Seebeck effect thermoelectromotive force and temperature difference have a linear relationship, which has the characteristics of repetition and stability. Secondly, applying an electric field to CFRP will produce a hot spot effect, that is an electrothermal effect [3].

However, it is worth noting that carbon fiber has a higher cost compared to other conductive materials, making it a certain limitation in the construction field. In addition, excessive carbon fiber content often leads to a decrease in mechanical properties and electrical conductivity. Therefore, the carbon fiber content needs to be quantitatively assessed and mixed with appropriate mixing techniques [4].

2.2. Nano Carbon Black Concrete

Nanofibers, nanotubes, carbon black and other nanomaterials are often combined with cement and mortar to form nanocomposite sensors. However, because nano carbon black not only has lower cost, but also has better interface properties, making nano carbon black materials become one of the first choices for intelligent materials. Nano carbon black has a large specific surface area and excellent electrical conductivity, when mixed into concrete, it can significantly reduce the resistivity of concrete, so that concrete from an insulator to a conductor. At the same time, appropriate addition can improve the mechanical properties of nano-carbon black composites to a certain extent, and increase the strength and durability of concrete. It can be used to make structural components with special properties, such as walls with better crack resistance and pavement with greater durability. This is mainly due to the filling effect and interface effect of nano carbon black particles in concrete.

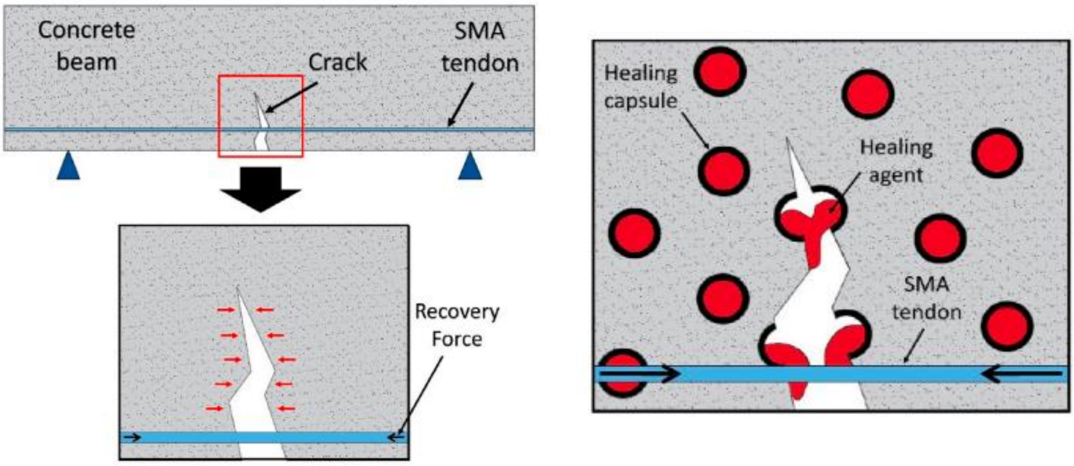
Nano carbon black concrete can also be combined with other intelligent materials to prepare intelligent concrete with self-sensing, self-healing and other functions. This intelligent concrete can monitor its own structural state in real time and automatically repair when damage occurs, thus improving the safety and durability of the building. For example, in Bridges, tunnels and other infrastructure, intelligent concrete can find and repair cracks and other damage in time, extending the service life.

However, the effect of replacing carbon black with nano carbon black or simply increasing the content of carbon black on improving the resistivity of concrete is limited. It is still necessary to further explore how to obtain the best comprehensive performance and cost through reasonable mixing and matching or secondary modification of carbon black [6].

2.3. SMA

SMA is an alloy that has a memory of its original form, and it can be restored to its original state through its own state or the external environment when it is deformed. SMA mainly has two characteristics: shape memory effect and superelasticity. Shape memory effect means that after plastic deformation, the alloy can complete the conversion between martensite and austenite by unloading or temperature change, while superelasticity can store energy at high temperature, thus realizing two important functions of self-centering and energy damping [7, 8].

SMA has a highly recoverable strain of 8%-10% after deformation, and many studies have shown that SMA can be self-healing by embedding or external installation into cement composites, especially in the case of cracks, material damage and deformation, and external loads. For example, Fig. 1 uses SMA in self-healing concrete to (a) close cracks through the restorative force generated by SMA, and (b) use healing agents in SMA and substrate to accelerate and improve the healing process [8]. Therefore, SMA is often used in the field of civil engineering, because it has passive control structure and active control damping of structural vibration, so it plays a good reinforcement and seismic control effect [7, 8]. It is especially widely used in earthquake-prone areas such as Japan, where SMA can achieve good material rebound after earthquakes and reduce the probability of house collapse.



(a) The resilience of the SMA closes the crack (b)The healing process of the SMA

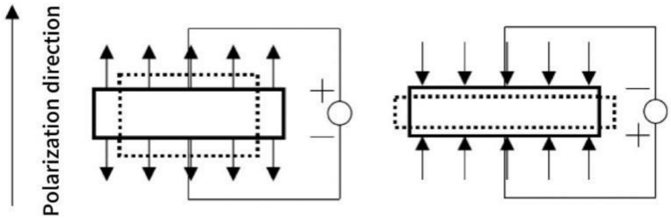
Figure 1. SMA is used for self-healing concrete [8]

In the field of civil engineering, Cu- and Fe-based alloys are the most widely used because of their lower cost, strong processability and good recovery speed. For example, Fe-base alloys can provide good pressure recovery and limiting effects in the reinforcement of reinforced concrete beams. Although NiTi alloy is one of the highest-quality SMAs. Due to its super elasticity and damping capacity, it can be used as a vibration isolation and damping device and external damping device. For example, it is used to control the vibration of bridge cables and reduce fatigue damage, as well as improve the resistance of buildings to typhoons and earthquakes. However, due to its high cost, its application in the construction field is limited to a certain extent [7, 8].

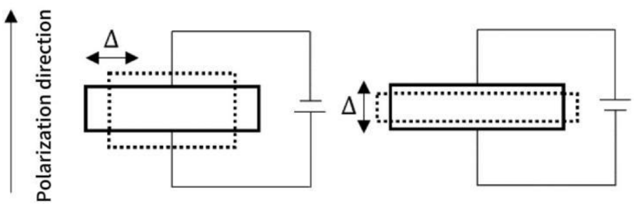
2.4. Piezoelectric Material

Piezoelectric material is a kind of special material that can produce current and pressure changes under pressure or current stimulation. Most of them are crystalloids, which integrate sensing and driving functions, and have electrodynamic coupling to related external stimuli.

At the end of the 19th century, scientists the Curie brothers discovered the piezoelectric effect in quartz crystals. This effect is due to the asymmetry of the lattice structure. When the external force acts on the piezoelectric material, the charge distribution in it will be uneven, resulting in a potential difference, resulting in a charge signal. This phenomenon is called the positive piezoelectric effect. Conversely, when an electric field is applied, the charge distribution inside the material also changes, causing mechanical motion, which is the inverse piezoelectric effect, as shown in Fig. 2 [9].



(a) Positive piezoelectric effect



(b) Reverse piezoelectric effect

Figure 2. Piezoelectric effect [9]

Piezoelectric materials can be divided into: inorganic piezoelectric materials, organic piezoelectric materials and composite piezoelectric materials. Inorganic piezoelectric materials include piezoelectric crystals and piezoelectric ceramics. Piezoelectric single crystals are called piezoelectric crystals, and piezoelectric polycrystals are called piezoelectric ceramics. Piezoelectric crystals such as quartz, lithium gallium, lithium germanate and so on. These materials have excellent piezoelectric properties, but at a higher cost. Piezoelectric ceramics are generally like barium lead acid, barium titanate, etc., which are often used to make transducers and filters. These materials are among the most widely used piezoelectric materials, with good piezoelectric properties and low cost. Organic piezoelectric materials are also known as piezoelectric polymers, such as polyvinylidene fluoride (PVDF) and so on. This kind of material is flexible, low density, low impedance, and high voltage voltage constant, the development is very rapid, in underwater acoustic ultrasonic measurement, pressure sensing, ignition detonation and other applications. The composite piezoelectric material is composed of sheet, rod, rod or powder piezoelectric material embedded in the organic polymer substrate material. They combine the advantages of various materials, have relatively excellent piezoelectric and mechanical properties, and play an important role in the fields of underwater sound, ultrasound, medicine and so on [10].

Piezoelectric materials are widely used in the field of civil engineering. First, structural damage identification and health monitoring. Because of its positive piezoelectric effect, piezoelectric materials can convert mechanical deformation into electrical signals, which provides a new solution for the health monitoring of civil engineering structures. For example, when the strain sensor occurs in the civil engineering structure, the piezoelectric sensor attached to the structure will generate charge, and the strain variable of the structure can be calculated by measuring the amount of charge, so as to achieve real-time monitoring of the structural strain. Second, structural vibration control and vibration reduction. The inverse piezoelectric effect of piezoelectric materials can convert electrical energy into mechanical energy, which provides a new technical means for structural vibration control and vibration reduction. For example, when the piezoelectric intelligent driver receives the control signal, it will produce the corresponding mechanical deformation, thus changing the vibration characteristics of the structure. Through the rational design of the driver layout and control strategy, the structural vibration can be effectively suppressed. The piezoelectric energy dissipation damper can convert the mechanical energy into electric energy and dissipate it in the process of structural vibration, thus reducing the vibration amplitude and energy of the structure. This kind of damper has the advantages of simple structure and good energy consumption effect, etc., and has been widely used in the vibration reduction and aseismic of civil engineering structures [9, 10].

3. Conclusion

The application of intelligent materials in civil engineering shows the vigorous trend and great potential of technological innovation in this field. These materials not only greatly enhance the safety, durability and sustainability of civil engineering structures, but also revolutionize the design, construction, operation and maintenance of civil engineering through real-time monitoring, precise control and intelligent response capabilities. The application of civil engineering intelligent materials has fully demonstrated its remarkable results and broad prospects in improving engineering performance, ensuring safety, energy saving and emission reduction, and promoting the intelligent transformation of the industry.

This paper mainly introduces four kinds of intelligent materials. CFRP is widely used in structural strengthening and other fields because of its high strength, durability and construction convenience, but its cost is high and construction is complicated. Nano-carbon black concrete has significant advantages in strengthening and conductive properties, but its application is still limited, and the dispersion and stability of the material need to be solved. SMAs have unique advantages in seismic resistance and self-healing due to their adaptive and self-healing properties, but cost and processing difficulty are the main limiting factors. Piezoelectric materials have excellent performance in structural health monitoring and vibration control, but the lack of large driving force piezoelectric drivers and power supply problems are current challenges. Especially in the measurement of large-scale civil engineering structures, the material can not be used directly.

Looking forward to the future, with the progress of science and technology and the deepening of research, the application prospect of intelligent materials in civil engineering is broad. On the one hand, through technological innovation and cost control, it is expected to reduce the production and use costs of intelligent materials, and promote their widespread application in large-scale projects. On the other hand, with the in-depth understanding of the performance mechanism of intelligent materials, the material design can be further optimized, improve its performance stability and durability, and meet the strict requirements of civil engineering for material properties. In addition, interdisciplinary research cooperation will also open up new ways for the application of intelligent materials in civil engineering, such as combining information technology, sensing technology and intelligent materials to achieve intelligent monitoring, control and maintenance of civil engineering structures.

In summary, although the application of intelligent materials in civil engineering faces many challenges, its unique advantages and potential indicate broad prospects for future development. With the continuous progress of technology and in-depth research, intelligent materials are expected to bring more innovation and change to the field of civil engineering.

References

[1] D.F. Wang, Research on Development and Application of Intelligent Materials in Civil Engineering, Building Technology Development 48 (2021) 62-63.

[2] W.Y. Xu, Research on Application of Intelligent Materials in Civil Road and Bridge Construction, Henan Science and Technology 41 (2022) 83-86.

[3] X.Y. Wang, Study on Mechanical Properties and Microstructure of Intelligent Concrete Materials, Changchun Institute of Technology, 2022.

[4] Q. Tian, J. Zhou, J.W. Hou, Z.W. Zhou, Z.M. Liang, M. Sun, J.X. Hu, J.D. Huang, Building the future: Smart concrete as a key element in next-generation construction, Construction and Building Materials 429 (2024) 136364.

[5] Y. Yang, Analysis of the development status and working mechanism of intelligent concrete material, Dwellinghouse 20 (2023) 61-64.

[6] J.Y. Xu, D.H. Yan, S. Xiao et al., Self-sensing functional fillers in concrete structures: Review, Journal of Southwest Jiaotong University (2024) 1-17.

[7] L.D. Xu, J.T, Zhao, M.F. Shi, X.Y. Zhang, Z.Q. Wang, Application of shape memory alloys and their composites, Technological innovation and application 33 (2021) 23-25+31.

[8] I. Abavisani, O. Rezaifar, A. Kheyroddin, Multifunctional properties of shape memory materials in civil engineering applications: A state-of-the-art review, Journal of Building Engineering 44 (2021) 102657.

[9] L. Yang, Bending performance of FRP-concrete composite pipe based on piezoelectric ceramic intelligent sensing, Shenzhen University, 2022.

[10] Z.H. Gao, Damage identification and monitoring of concrete based on PTZ, Taiyuan University of Technology, 2021.