Research on the Synergistic Mechanical Mechanism of New Energy Storage Materials and Civil Structures

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Abstract: This paper focuses on the research of the synergistic mechanical mechanism between new energy storage materials and civil structures. Firstly, it expounds the development background and characteristics of new energy storage materials, as well as the significance of civil structures in contemporary architecture. Then, an in-depth analysis is conducted on the mechanical principles of the synergy between new energy storage materials and civil structures, including aspects such as stress distribution and deformation coordination under their interaction. At the same time, explore the collaborative improvement of the performance of civil structures, such as enhancing structural stability and improving seismic performance, etc. Finally, the future development direction of this field is prospected, aiming to provide theoretical references for the wide application of new energy storage materials in civil engineering.

Keywords: New Energy Storage Materials; Civil Engineering Structure; Collaborative Mechanics Mechanism

1. Introduction

1.1 Research Background and Significance

In the current context where the global energy crisis is becoming increasingly severe and the concept of sustainable development has taken root in people's hearts, seeking efficient and environmentally friendly energy storage methods has become a key focus of research in various fields. New energy storage materials, with their unique energy storage properties, have shown great potential in energy storage and conversion [1]. Meanwhile, as an important carrier of human life and production activities, the safety and functionality of civil structures are of vital importance. Combining new energy storage materials with civil structures not only enables effective energy storage and utilization but also enhances the performance of civil structures, bringing about significant economic and social benefits. This synergy has brought new development opportunities to the field of civil engineering and is of great significance for promoting the green transformation and sustainable development of the construction industry [2].

1.2 Current Research Status at Home and Abroad

Foreign countries have started earlier in the collaboration between new energy storage materials and civil structures and have already carried out a series of research works. In terms of material research and development, we constantly explore the performance optimization and preparation process improvement of new energy storage materials. In terms of structural application, through experimental and simulation studies on the interaction mechanism between energy storage materials and civil structures, some phased achievements have been made. For instance, a research team in the United States applied phase change energy storage materials to building walls. Through experiments, they found that this material could effectively regulate indoor temperature and reduce building energy consumption [3]. Although domestic related research started relatively late, it has developed rapidly. In recent years, many research institutions and universities have increased their investment in this area and made considerable progress in the localized research and development of new energy storage materials as well as the collaborative design with civil structures. For instance, a team from a domestic university developed a new type of energy storage concrete and applied it to bridge structures, which enhanced the seismic performance of the bridges [4]. However, the overall research is still in the exploratory stage at present, and the in-depth understanding of the mechanism of cooperative mechanics is not yet comprehensive enough, which requires further in-depth study.

2. Overview of New Energy Storage Materials

2.1 Classification and Characteristics of New Energy Storage Materials

New energy storage materials refer to a category of materials that support the development of new energy and have energy storage functions. According to their usage purposes, they can be classified into electricity storage materials, heat storage materials and hydrogen storage materials [5].

Energy storage materials mainly include lithium-ion batteries, sodium-ion batteries, flow batteries, etc. Lithium-ion batteries are currently the main type of energy storage technology in the power system. This technology is mature and developing the fastest, featuring high energy density, long life, and rapid charging and discharging. They are widely used in power system peak shaving, new energy vehicles, home energy storage, and other fields. Although sodium-ion batteries are still in the experimental demonstration stage, they have initially met the conditions for industrialization access. Due to their advantages such as abundant resources and low cost, they are regarded as an important supplement to lithium-ion batteries. Flow batteries, such as all-vanadium flow batteries, have formed initial standardized products and are ready for demonstration and promotion. They have the advantages of intrinsic safety and large-capacity energy storage, and are competitive in specific application scenarios [7].

Among heat storage materials, phase change energy storage materials absorb or release heat through the phase change process of substances, achieving the storage and release of thermal energy. They have the characteristics of high energy storage density and stable temperature control, and play an important role in fields such as building temperature control, electronic component temperature control, and textile temperature regulation [8]. For instance, the application of phase change energy storage materials in building envelope structures can absorb heat during the day and release it at night, regulate indoor temperature, reduce reliance on traditional air conditioning systems, and lower energy consumption.

Hydrogen storage materials have advantages such as being clean and low-carbon, having a long storage time, and being able to travel long distances. They have obvious advantages in large-scale and long-distance energy storage and transportation scenarios. At present, magnesium-based hydrogen storage materials and others have received extensive attention, and researchers are constantly exploring the optimization of their performance and the improvement of their preparation processes.

2.2 Application Potential of New Energy Storage Materials in Civil Engineering

New energy storage materials have broad application potential in civil engineering. In terms of building energy conservation, phase change energy storage materials can be applied to walls, roofs and other parts, regulating indoor temperature by absorbing and releasing heat, reducing reliance on traditional air conditioning systems and lowering energy consumption. In the field of intelligent buildings, by integrating battery-based energy storage materials and sensor technology, it is possible to achieve self-sufficiency and intelligent management of building energy. For instance, solar panels are used to collect energy and store it in batteries to power the lighting, ventilation and other systems of buildings. In addition, in infrastructure construction, new energy storage materials can also be used for health monitoring and energy supply of structures such as bridges and tunnels, enhancing the safety and reliability of the structures.

3. Basic Characteristics and Requirements of Civil Structures

3.1 Types and Functions of Civil Structures

Civil structures cover a variety of types, including buildings (such as residential buildings, commercial buildings, industrial plants, etc.) and infrastructure (such as bridges, tunnels, DAMS, etc.). Different types of civil structures have different functions. Buildings mainly provide people with living and working spaces, meeting the needs of residence, office work, production, etc. Infrastructure, on the other hand, undertakes important functions such as transportation, water resource allocation, and energy transmission, playing a crucial role in the normal operation of society and economic development.

3.2 Requirements for Materials and Properties of Civil Structures

Civil structures have strict requirements for materials and performance. In terms of mechanical properties, structural materials need to have sufficient strength, rigidity and stability to withstand the action of various loads (such as self-weight, wind load, seismic load, etc.) and ensure the safety of the structure. In terms of durability, the material should be able to resist the erosion of environmental factors, such as chemical corrosion and freeze-thaw cycles, to ensure the stability of the structure's performance during long-term use. In addition, as people's demands for the quality and functionality of buildings increase, civil structures also need to have good heat insulation, sound insulation, fire resistance and other properties. The synergy between new energy storage materials and civil structures needs to meet these basic requirements and, on this basis, achieve efficient energy utilization and further improvement of structural performance.

4. The Mechanical Principles of the Synergy between New Energy Storage Materials and Civil Structures

4.1 The Mechanical Basis of their Interaction

The synergy between new energy storage materials and civil structures is based on the mechanical interaction between the two. When new energy storage materials are applied to civil structures, they will come into contact with and connect with structural components. Under the action of loads, structural components will deform, and this deformation will be transferred to the energy storage materials connected to them. Meanwhile, the mechanical properties of energy storage materials themselves will also have an impact on the force on structural components. For instance, parameters such as the elastic modulus and Poisson's ratio of energy storage materials can affect the stress distribution of the structure under force. From the perspective of mechanical equilibrium, the interaction between the two needs to meet the condition of force equilibrium, that is, the external and internal forces acting on the structure as well as the reaction force exerted by the energy storage material on the structure should reach equilibrium.

4.2 Stress Distribution and Deformation Coordination During the Collaborative Process

In the collaborative process, the coordination of stress distribution and deformation is a key issue. The introduction of new energy storage materials will change the original stress distribution state of civil structures. For instance, embedding energy storage materials in key parts of a structure may alleviate the stress concentration at that location and distribute the stress more evenly throughout the surrounding structure. Meanwhile, in order to ensure the overall performance of the structure, it is necessary to achieve deformation coordination between the energy storage materials and the structural components. This means that under the action of loads, the two should have similar deformation characteristics to avoid excessive stress differences caused by uncoordinated deformations, which could lead to structural damage. Through reasonable design and material selection, energy storage materials can be coordinated with civil structures during the force application process, achieving a good stress distribution and deformation coordination.

4.3 The Influence Mechanism of Synergy on the Mechanical Properties of Civil Structures

The synergy between new energy storage materials and civil structures has multiple influences on the mechanical properties of the structures. In terms of strength, energy storage materials can play a reinforcing role. For instance, when certain high-strength energy storage materials are combined with structural components, the load-bearing capacity of the components can be enhanced. In terms of stiffness, the synergistic effect can improve the overall stiffness distribution of the structure, making it more stable under force. In addition, synergy can also enhance the seismic performance of the structure. Energy storage materials can reduce the damage caused by earthquakes to structures by absorbing and dissipating seismic energy. Its mechanism of action mainly includes the damping characteristics of energy storage materials, which can consume the energy of seismic waves, as well as the interaction between energy storage materials and structures, which changes the dynamic characteristics of the structure and reduces its seismic response.

5. Synergistic Improvement of Civil Structure Performance

5.1 Enhance Structural Stability

The synergy between new energy storage materials and civil structures helps enhance the stability of the structures. Under complex environmental loads, such as strong winds and earthquakes, structures are prone to instability. The application of energy storage materials can alter the dynamic characteristics of structures and enhance their anti-overturning and anti-sliding capabilities. For instance, by embedding energy storage devices in the foundation of high-rise buildings, when the building is subjected to lateral forces, the energy storage devices can provide additional resistance through their own mechanical properties, preventing the building from tilting or sliding too much, thereby enhancing the overall stability of the structure.

5.2 Improve Seismic Performance

Seismic performance is one of the important indicators of civil structures. New energy storage materials have unique advantages in improving the seismic performance of structures. As mentioned earlier, the damping characteristics of energy storage materials can absorb and dissipate seismic energy. During an earthquake, the interaction between structures and energy storage materials can cause the seismic energy to attenuate during transmission, reducing the energy transferred to the main body of the structure. In addition, energy storage materials can also adjust the natural vibration period of the structure, prevent the structure from resonating with seismic waves, and thereby reduce the degree of damage to the structure during earthquakes. Through reasonable collaborative design, civil structures can have better toughness and safety in earthquakes.

5.3 Enhance Structural Durability

Civil structures will be affected by various environmental factors during long-term use, leading to a decline in durability. The application of new energy storage materials can improve the durability of structures to a certain extent. For instance, some energy storage materials with self-healing functions can repair the tiny cracks in the structure through their own chemical reactions or physical actions, preventing the further expansion of the cracks and thus protecting the structure from erosion by the external environment. In addition, energy storage materials can also improve the insulation and waterproofing performance of structures, reduce structural damage caused by temperature changes and water penetration, and extend the service life of structures.

6. Challenges Faced and Future Development Directions

6.1 Challenges Faced by Current Research

At present, the research on the collaborative mechanical mechanism between new energy storage materials and civil structures is confronted with numerous challenges. In terms of materials, the performance of new energy storage materials is still not stable enough. Their mechanical properties, energy storage performance, etc. may change significantly under different environmental conditions, which brings difficulties to the coordinated application of civil structures. In terms of structural design, there is a lack of unified design standards and norms. How to rationally integrate energy storage materials into civil structures to achieve the best synergistic effect still requires further exploration. In addition, long-term performance monitoring and evaluation during the collaborative process is also a challenge. Currently, there is a lack of effective monitoring means and evaluation methods, making it difficult to accurately grasp the performance changes of the collaborative structure during long-term use.

6.2 Future Development Direction

In the future, research on the collaborative mechanical mechanisms of new energy storage materials and civil structures will develop in multiple directions. In terms of material research and development, efforts will be made to develop new types of energy storage materials with more stable and efficient performance, improve the mechanical properties and energy storage efficiency of materials, and at the same time reduce material costs. In terms of structural design, a complete set of design standards and norms will be established, and more scientific and reasonable collaborative design methods will be developed to achieve the optimal integration of energy storage materials and civil structures. In addition, with the development of technologies such as the Internet of Things and big data, the intelligent monitoring and evaluation of collaborative structures will be strengthened, and the performance status of the structures will be grasped in real time, providing a guarantee for the safe operation of the structures. At the same time, the scope of collaborative applications will also be expanded, not only to the fields of construction and infrastructure, but also to explore the application possibilities in broader fields such as marine engineering and aerospace.

7. Conclusion

The research on the collaborative mechanical mechanism of new energy storage materials and civil structures is a challenging yet highly promising field. Through an in-depth understanding of new energy storage materials and an analysis of the mechanical principles of their interaction with civil structures, we have recognized that the synergy of the two can bring about multiple performance improvements to civil structures, including enhancing structural stability, improving seismic performance, and increasing structural durability. However, at present, research in this field still faces challenges such as unstable material properties, lack of design standards, and difficulties in long-term performance monitoring. In the future, with the continuous development of materials science, structural engineering and information technology, we have every reason to believe that the collaborative application of new energy storage materials and civil structures will achieve greater breakthroughs, opening up new paths for the sustainable development of the civil engineering field.

References

[1] Alami, A. H. (2020). Mechanical energy storage for renewable and sustainable energy resources (p. 71). Cham, Switzerland: Springer.

[2] Kumar, R., Lee, D., Ağbulut, Ü., Kumar, S., Thapa, S., Thakur, A., ... & Shaik, S. (2024). Different energy storage techniques: recent advancements, applications, limitations, and efficient utilization of sustainable energy. Journal of Thermal Analysis and Calorimetry, 149(5), 1895-1933.

[3] Wu, M., Liu, C., & Rao, Z. (2022). Experimental study on lauryl alcohol/expanded graphite composite phase change materials for thermal regulation in building. Construction and Building Materials, 335, 127400.

[4] Li, J., Fomin, N. I., Xiao, S., Yang, K., Zhao, S., & Yang, H. (2025). Seismic enhancement techniques for reinforced concrete frame buildings: a contemporary review. Buildings, 15(6), 984.

[5] Mukherjee, A., Srivastava, P., & Sandhu, J. K. (2023). Application of smart materials in civil engineering: A review. Materials Today: Proceedings, 81, 350-359.

[6] Ahmed, M. D., & Maraz, K. M. (2023). Revolutionizing energy storage: Overcoming challenges and unleashing the potential of next generation Lithium-ion battery technology. Materials Engineering Research, 5(1), 265-278.

[7] Kumar, S., Nag, N., Kumari, S., Sarkar, I. J. R., & Singh, A. (2023). Vanadium Redox Flow Batteries for Large-Scale Energy Storage. In Recent Technologies for Waste to Clean Energy and its Utilization (pp. 79-109). Singapore: Springer Nature Singapore.

[8] Podara, C. V., Kartsonakis, I. A., & Charitidis, C. A. (2021). Towards phase change materials for thermal energy storage: classification, improvements and applications in the building sector. applied sciences, 11(4), 1490.

