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High-performance lightweight aggregate concrete research and mechanical property analysis: A review

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Abstract: In the current era where prefabricated construction is dominant, under the trends of industrialization, mechanization, and green construction, a series of experiments and explorations have been conducted in a multidisciplinary approach of materials engineering, structural engineering, and civil engineering. This paper presents an overview of existing domestic and international research on high-performance lightweight aggregate concrete used for prefabricated interior partition walls. This includes: research and design of high-performance lightweight aggregate concrete and initial mechanical property analysis; determination of its significant optimization effect for preparing prefabricated interior partition panels; seeking ways to further enhance the performance of lightweight aggregate concrete-made interior partition panels and increase their applicability in building assembly. Taking into account engineering practical applications, the future application prospects of high-performance lightweight aggregate concrete in prefabricated interior partition panels are discussed, alongside further research directions and suggestions. The research outcomes of this paper are of great significance in promoting the development of industrialized construction and green buildings.

Keywords: Prefabricated structures; Interior partition panels; Lightweight aggregate concrete; High-performance concrete; Mix design.

1. Introduction

Prefabricated interior partition panels have attracted significant attention in the construction industry due to their lightweight and high-strength characteristics. Compared to traditional concrete, their limitations in terms of weight and ease of handling are particularly prominent. Therefore, the development of high-performance lightweight aggregate concrete is crucial to meet the specific needs of prefabricated interior partition panels. Lightweight aggregate concrete, with its significant strength-to-weight ratio advantage, stands out for its core features of being lightweight and high-strength compared to ordinary concrete. In fields such as high-rise buildings, large-span bridges, and marine engineering, where material performance requirements are stringent and structural dead load ratios are high, lightweight high-strength lightweight aggregate concrete demonstrates strong market competitiveness.

2. Problem Statement

Traditional interior partition panels have many issues, such as being heavy (ordinary concrete panels), poor durability (gypsum panels), and low fire resistance (wood panels), which affect the overall quality improvement of prefabricated buildings. In order to address these issues, lightweight aggregate concrete has become an ideal choice because it has advantages such as low apparent density, excellent thermal insulation properties, high fire resistance, and strong durability. By using lightweight aggregate concrete in interior partition panels, the self-weight of prefabricated components can be significantly reduced, facilitating transportation and installation, while also enhancing the thermal insulation and seismic performance of building structures. The application of this technology not only improves the characteristics of building materials but also helps to enhance the overall quality and performance of building structures, providing a more reliable solution for prefabricated construction.

3. Development and Application of Lightweight Aggregate Concrete

The United States began utilizing lightweight aggregate concrete early on, with the successful development of techniques for producing lightweight aggregates from shale in the early 20th century, resulting in lightweight aggregate concrete with strengths of up to 30 MPa. It was quickly widely used in various construction projects. For example, a bridge in California, USA utilized lightweight aggregate concrete as a construction material. Subsequently, Japan started researching high-performance concrete to improve the durability and workability of concrete, achieving certain successes. Nowadays, a specially designed ultra-lightweight aggregate concrete, suitable for producing prefabricated partition walls, has been developed using waste glass as raw material. Various materials have been put into use for the production of prefabricated concrete partition walls, including expanded shale lightweight aggregates. Despite China's relatively late start in the field of lightweight aggregate concrete, with the first application of lightweight aggregate concrete on the Luohe Bridge in Henan not occurring until 1960, the application of lightweight aggregate concrete in China is gradually improving with the continuous advancement of technology and accumulation of experience. The application of this material can not only improve the performance and durability of concrete structures, but also contribute to the efficient use of resources and environmental protection. However, as of now, the quality of lightweight aggregate in China remains poor, leading to a slow development. The low strength and high density are issues hindering the development of lightweight aggregate concrete, mainly playing a role in non-load-bearing structures of

buildings and bridges, rather than being able to bear load-bearing roles, which limits its development. By the end of the last century, the technology of lightweight aggregate concrete rapidly developed, forming a certain scale of production capacity for high-strength lightweight aggregate concrete. Large buildings using lightweight aggregate concrete include the Zhuhai International Convention Center. Currently, the application of lightweight aggregate concrete in China is still mainly concentrated in low-strength non-load-bearing structures. Compared to extensive use abroad, there is still a significant gap compared to developed countries.

Regarding lightweight aggregate concrete and its work performance, Murat Kurt et al. studied the influence of blast furnace slag on the self-compacting properties of lightweight aggregate concrete made with pumice. The research indicated that increasing the proportion of pumice aggregate would cause the aggregates to float easily, thus reducing the work performance. Due to the relatively high-water absorption rate of lightweight aggregates, continuous water absorption can affect the uniformity of concrete mixing, suggesting the use of saturated lightweight aggregates. Liu Li et al. conducted related experimental studies, focusing on the effects of mix slump, types of lightweight coarse aggregates, mineral admixtures, and thickeners on the segregation of lightweight coarse aggregates. Through experiments, they analyzed the impact of these factors on concrete performance: an increase in mix slump and a decrease in viscosity would exacerbate the phenomenon of lightweight aggregate floating; changes in the density grade and particle size distribution of lightweight aggregates would also affect floating, with smaller particle-sized lightweight aggregates helping to reduce floating. Wang Zhijun studied the influence of mineral admixtures and fiber materials on the anti-segregation performance of lightweight aggregate concrete. The research showed that adding fly ash, slag powder, or fiber materials can enhance the anti-segregation performance of lightweight aggregate concrete, but an excessive amount of fiber can affect the fluidity of the mixture.

4. Study on the Mechanical Properties and Mix Design of Lightweight Aggregate Concrete

In terms of the mechanical properties of lightweight aggregate concrete, Kozo Onoue et al. conducted a study on the mechanical performance of lightweight aggregate concrete using volcanic pumice. The research indicates that lightweight aggregate concrete with volcanic pumice exhibits lower strength and elastic modulus compared to limestone concrete. Alessandro P. Fantilli et al. investigated fiber-reinforced lightweight concrete panels for elevated bridge maintenance. The study showed that the addition of an appropriate amount of fibers in elevated bridge maintenance can enhance the ductility of lightweight concrete panels, transforming the failure mode from brittle to ductile, which is suitable for enhancing lightweight concrete structures. Li Jingjun explored the impact of plastic steel fibers on the mechanical properties and microstructure of lightweight aggregate concrete. The study revealed that plastic steel fibers have a certain beneficial effect on the compressive strength and failure mode of lightweight aggregate concrete, specifically transitioning the failure mode from brittle destruction to ductile fracture.

Regarding the primary mix parameters of lightweight aggregate concrete, Liu Xinyi et al. investigated the influence of water-cement ratio and sand ratio on the compressive strength and density of lightweight aggregate concrete. The research revealed that the water-cement ratio significantly affects compressive strength, while the sand ratio has a more pronounced impact on density. Furthermore, the study on foam-EPS concrete by Wu Yuanyuan et al. highlighted that density is directly proportional to dry apparent density, with higher density contributing to greater compressive strength. In terms of the high-temperature performance of lightweight aggregate concrete, Kong Qingxia research focused on the development and mechanical properties study of high-performance lightweight aggregate concrete using fiber reinforcement for prefabricated internal partition walls. The study indicated that under high-temperature conditions, lightweight aggregate concrete experiences increased and widened cracks, as well as loosening of cement stones. With the application of high temperatures, polypropylene fibers evaporate to provide channels for water vapor, aiding in reducing excess vapor pressure, preventing high-temperature concrete bursting, and thereby enhancing the fire resistance of concrete.

Moreover, compared to regular coarse aggregates, lightweight coarse aggregates such as expanded clay have strengths and elastic moduli closer to the dry cement paste. As a result, lightweight aggregate concrete exhibits lower levels of cracking in the interface zone under high-temperature conditions compared to conventional concrete. In the investigation of thermal insulation properties, the influence of adding bottom ash to lightweight aggregate concrete was examined. In their exploration of using bottom ash in the production of lightweight aggregate concrete, Binyu Zhang et al. concluded that, when 100% bottom ash was used, the lightweight aggregate concrete demonstrated comparable workability and compressive strength to regular aggregate concrete. An increase in bottom ash content led to a reduction in the dry density of lightweight aggregate concrete due to the lower density of bottom ash. Xia Chengbin observed that with a bottom ash substitution rate below 50%, the concrete exhibited a higher ratio of preparation strength to dry density, and the thermal conductivity decreased with an increase in bottom ash content. This indicates that a moderate addition of bottom ash does not compromise the concrete's strength, making it suitable for prefabricated building structures. Additionally, lightweight expanded clay aggregate concrete offers advantages such as being lightweight, excellent thermal insulation properties, and ease of construction, making it suitable for enhancing the thermal insulation performance of buildings.

5. Research on the Preparation of Porous Lightweight Aggregate Concrete

Currently, both domestically and internationally, there is limited research on low-strength self-compacting lightweight aggregate concrete and its application technology in interior partition walls. The preparation method of porous lightweight aggregate concrete involves enveloping specific particle sizes of lightweight coarse aggregates with cement paste. Xiuqin Liang conducted experimental research on the performance of porous concrete with expanded clay aggregate framework, revealing that the early strength development of porous concrete with expanded clay aggregates is rapid, with a 7-day

strength reaching 75% of the 28-day strength. The addition of materials such as fly ash and slag powder tends to reduce the strength of porous concrete, whereas incorporating polymer emulsion can significantly enhance its strength. Studies by Jihui Zheng et al. indicated that in shale expanded clay aggregate porous concrete, the cement-to-aggregate ratio (binder material/aggregates) has the most significant impact on the strength and porosity of the concrete. The research found a proportional relationship between strength and porosity, indicating that as the strength of the concrete increases, the porosity decreases. Furthermore, shale expanded clay aggregate concrete shows rapid early strength development, implying good early strength performance of the material. QI Liu et al. investigated the preparation of shale expanded clay aggregate porous concrete, revealing that the dry density of this concrete is only one-third of that of regular porous concrete. The researchers also observed that the particle size distribution of coarse aggregates has a significant influence on the compressive strength of shale expanded clay aggregate porous concrete, emphasizing the vital importance of selecting and controlling coarse aggregate distribution for the concrete's performance. The study conducted by Yuwadee and Zaetang explored the effects of incorporating lightweight aggregates in porous concrete. Silica fume and pumice were used as lightweight aggregates in the porous concrete, and the results showed that the use of lightweight aggregates significantly reduces the density and thermal conductivity of porous concrete by around 3 to 4 times. Additionally, with compressive strengths ranging from 2.5 MPa to 6.0 MPa at 28 days, it is evident that adding lightweight aggregates can maintain the concrete's strength within a certain range. Increasing the paste content further improves the workability of the concrete, which is of great significance for the practical application of porous concrete.

The use of air-entraining admixtures in concrete can improve its workability, cohesion, and water retention, enhance durability properties such as freeze-thaw resistance and impermeability after concrete hardening, but may have a negative impact on the compressive strength of concrete. High-quality fly ash can enhance the workability and durability of concrete, positively affecting the development of compressive strength in later stages of concrete. Additionally, the incorporation of air-entraining admixtures and fly ash helps reduce the volumetric density difference between cement mortar and lightweight aggregate concrete, improving the homogeneity of concrete. The use of high-efficiency water reducers can produce concrete with high fluidity and low water-cement ratio, especially when used in combination with fly ash, contributing to balancing the relationship between workability, strength, and durability of concrete. This comprehensive approach of utilizing different admixtures and additives helps enhance the performance of concrete, making it more suitable for various engineering applications and improving the overall quality and durability of concrete to a certain extent.

6. Application of Porous Concrete in Wall Panel Technology

Currently, porous concrete is widely utilized in applications such as road surfacing materials or vegetated concrete materials, but its use in wall panels remains relatively limited. Furthermore, there is a scarcity of experimental research on incorporating lightweight aggregates into porous concrete. The production process of lightweight partition panels does not comply with national standards. Although the national government has introduced relevant production standards, some companies fail to adhere to the required operational procedures specified in the national standards when manufacturing lightweight partition panels, resulting in substandard product quality. This non-compliance may lead to the dry shrinkage value of lightweight partition panels failing to meet the requirements, affecting the surface flatness of the panels. Consequently, uneven thickness during construction may arise, causing discrepancies in the thickness shrinkage coefficient that fall short of the stipulated standards, ultimately leading to the formation of cracks. Using lightweight partition panels that have not reached the necessary maturity at the construction site can lead to continued hydration shrinkage of the panels, resulting in cracks. Panels with insufficient curing time may not meet the expected performance requirements during construction, making them prone to quality issues.

The interface transition zone between mortar and coarse aggregate in concrete is a critical component of concrete structures, exerting a crucial influence on the mechanical performance and durability of concrete. One of the advantages of lightweight aggregate concrete is its ability to store water in internal pores, gradually releasing it after concrete hardening, which promotes the cement hydration reaction in the interface transition zone, enhancing its compactness. As a result, lightweight aggregate concrete exhibits good impermeability, freeze-thaw resistance, and resistance to chemical corrosion. Additionally, the porous structure of lightweight aggregate provides space for stress deformation within the concrete, thereby reducing internal stresses.

In the production process of lightweight partition panels, special attention needs to be given to the issue of oil contamination at the seams of the panels. During the forming process, the panels of lightweight partition panels must undergo demolding. To facilitate effective demolding, a demolding agent should be used during production and applied to the side edges of the panel molds, helping the panels to demold smoothly. Although waste engine oil can serve as a demolding agent for lightweight partition panels, reducing production costs, its drawbacks must be noted, as it may compromise the bonding effectiveness between the panels and the joint mortars. Cracking issues in lightweight partition panels often arise during the installation phase in the construction process. Workers are required to fill the lightweight partition panel seams with joint mortar in the joint grooves and strictly adhere to installation requirements. However, the use of regular cement mortar may result in insufficient filling of joint mortar due to its tendency to shrink and poor adhesion during the hardening process, potentially leading to instances of cement mortar detachment. These issues further contribute to the occurrence of cracks in lightweight partition panels after installation, significantly impacting the overall quality and stability of the wall structure. Therefore, the selection of appropriate materials and correct operational methods during construction is crucial to ensure the quality of lightweight partition panel installation.

Lightweight aggregate concrete lacks active components and does not exhibit the conditions for alkali-aggregate reactions, consequently enhancing the structure's durability. Its diverse porous structure allows some pores to be filled with water, while others remain empty. During freezing cycles,

these pores can absorb the expansion caused by water crystallization, leading to superior frost resistance in lightweight aggregate concrete compared to conventional concrete. Furthermore, the resistance of lightweight aggregate concrete to alkali-aggregate reactions surpasses that of ordinary concrete due to the formation of a high-calcium, low-alkali siliceous gel as a reaction product of lightweight aggregate. This gel demonstrates minimal or no swelling upon water absorption, enabling lightweight aggregate concrete to effectively mitigate the risk of alkali-aggregate reactions. These attributes bestow lightweight aggregate concrete with improved durability and an extended service life in engineering applications.

7. Conclusion

(1) With the flourishing development of the construction industry and the increasing prevalence of green building concepts, high-performance lightweight aggregate concrete, as the core material for prefabricated interior partition walls, is gradually garnering widespread attention in the industry.

(2) Existing research efforts are predominantly focused on developing a novel, specifically designed high-performance lightweight aggregate concrete for prefabricated interior partition walls and delving deep into its mechanical properties. Through meticulous mix design, careful selection of admixtures, and continuous optimization of production processes, compliant lightweight aggregate concrete has been successfully developed.

(3) Research methods regarding the mechanical behavior of lightweight aggregate concrete and its influencing factors also encompass numerical simulations and theoretical analyses. These research outcomes not only deepen the understanding of the mechanical properties of lightweight aggregate concrete but also provide robust theoretical support for further optimizing its manufacturing processes and enhancing its performance.

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