Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

A Review of Yangshao Lightweight Concrete: The Oldest Concrete in China

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

***Abstract*—Yangshao lightweight concrete, recognized as the oldest form of concrete in Chinese history, was unearthed at the Dadiwan archaeological site in Gansu Province, China. This paper provides a comprehensive review of the physical and mechanical properties, reaction mechanisms, and engineering applications of Yangshao lightweight concrete, drawing on both domestic and international research findings. (1) The primary constituents of Yangshao lightweight concrete include calcium nodules, ginger nuts, and red clay. The fabrication process entails crushing, roasting, grinding, and sieving these materials. (2) This concrete displays notable characteristics such as low volumetric weight, high porosity, and low apparent density. Remarkably, it maintains compressive strength comparable to that of modern cement mortar with a strength rating of 10 MPa, even after over 5,000 years. The mechanical properties, including tensile, compressive, and flexural strengths, are influenced by the firing temperature and the specifics of the firing process. (3) The mineral composition predominantly comprises calcite with minor quantities of quartz, while dendritic hydrated tricalcium aluminate and visibly crystalline hydrated calcium silicate are also present. The primary reaction mechanism involves the hydration reactions of β-type calcium silicate and dicalcium aluminosilicate, leading to the formation of hydrated calcium silicate and hydrated dicalcium aluminosilicate that enhance the strength of the air-hardened concrete. (4) Additionally, modifications of Yangshao lightweight concrete using metakaolin, quartz sand, fly ash, and other materials have been found to improve its properties, rendering it suitable for applications such as soil reinforcement, crack grouting, and battlefield repairs. In conclusion, Yangshao lightweight concrete exhibits outstanding physical and mechanical properties, has a broad spectrum of engineering applications, and holds a promising prospect for future development**

Keywords—Yangshao lightweight concrete, raw materials, physico-mechanical properties, reaction mechanism, engineering applications

I. INTRODUCTION

Concrete has a long history as a composite material, its origins tracing back to ancient civilizations[1]. Archaeological and historical documents show the earliest examples of concrete use appearing in the pre-pottery Neolithic period[2 Ancient Egypt subsequently mastered a technique of mixing lime with river sand to create a mortar, described as "wheat paste," which was used to build magnificent structures such as the pyramids[4 Subsequently, the ancient Babylonians, Greeks, and Romans further developed concrete technology[6-8] The Romans utilized lime and volcanic ash as binders, producing a material similar to modern cement, widely employed in urban buildings and public works[9 These ancient applications of concrete not only demonstrate the innovative spirit of ancient builders in materials science, but also profoundly impacted the development of modern concrete technology[11-14 Therefore, studying the use of ancient concrete is of great significance for understanding the influence of materials technology advancements on architectural and engineering development, and it can provide

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

valuable historical context and inspiration for innovation in modern concrete technology.

While during the Yangshao period, the use of limestone likely led to the production of hydraulic cementitious materials, such as hydraulic lime, due to the presence of argillaceous or siliceous minerals[15-17]. The late 1970s saw the discovery of over 200 ruins from the Yangshao period in Dadiwan, Qin'an, Gansu Province, China[18-23]. These ruins, dating back more than 5,000 years to the middle Yangshao period, were utilized for gatherings, sacrifices, or religious ceremonies. The floors of these sites are made of concrete consisting of artificially fired calcium nodules as a light aggregate, calcined ginger nuts and a small amount of red clay as a cementitious material, collectively known as “Yangshao Lightweight Concrete”, which is the earliest known concrete material in China[24].

This review aims to synthesize research findings on Yangshao lightweight concrete, both domestically and internationally. It explores the historical context of its discovery, the composition of raw and mineral materials, reaction mechanisms, imitation technologies, physical and mechanical properties, modification research, and its engineering applications. Furthermore, it proposes new insights into the trends of domestic materials for the preservation and reinforcement of cultural heritage, aiming to enhance their application in the protection, reinforcement, and restoration of cultural heritage projects.

II.OVERVIEW OF DADIWAN SITE

A. Location Overview and Excavation History

The Dadiwan site is located in Shaodian Village, Wuying Township, northeast of Qin'an County, Tianshui City, Gansu Province, approximately 102 kilometers from Tianshui City (Fig.1). This site stands as a significant cultural landmark from the early Neolithic period, covering the early, middle, and late phases of the Yangshao Culture. Spanning a rich tapestry of 3,000 years, Dadiwan is notable for its considerable size and the richness of its cultural artifacts, marking it as a particularly rare and important find in the field of Chinese archaeology. Recognized by the scholarly community, the Dadiwan Archaeological Site is heralded as one of the top 100 major archaeological discoveries in China during the 20th century[24,25].

The Dadiwan site was officially recognized as a provincial cultural relic protection unit by the Gansu Provincial People's Government in 1958. Extensive archaeological excavations were carried out at the site from the autumn of 1978 to 1984 during its third phase by the cultural relics team from the Gansu Provincial Museum. These excavations uncovered over 200 human settlement sites from the Yangshao period. Additionally, further excavations were conducted by the Gansu Provincial Institute of Cultural Relics and Archeology, in collaboration with other organizations, from May 2006 to October 2008. These efforts revealed traces of human activities at the site dating from 8,000 to 60,000 years ago.

Fig.1. The geographical location of the Dadiwan site[26].

Fig.2. F901 Yangshao ruins map[27].

International Journal of Engineering Research & Technology (IJERT)
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Vol. 14 Issue 06, June - 2025

B. Discovery of Yangshao Cement

The architectural remains at Dadiwan are monumental in scale and intricate in design. Notably, House F-901, hailed by archaeologists as a 'primitive palace,' represents the largest and most advanced early architectural structure known in China, as illustrated in Fig.2. The main chamber of F-901 shares the same floor area as another large structure, House F-405, with an interior space of 150 square meters. Both buildings exhibit a well-organized layout, characterized by axial symmetry, coherent spatial relationships, and a clear hierarchy in design.

Researchers Li Zuixiong, Lang Shude, and Zhao Jianlong conducted an in-depth analysis of the site's ground structure, focusing on houses F-901 and F-405[27-29]. Their study revealed that these houses featured a four-layer floor construction. For F-901, the initial layer is a thin raw slurry ground surface, about 2-3mm thick. This is followed by a second layer of concrete, approximately 200mm thick, utilizing fired granular hollow calcium nodules as aggregates and calcined ginger nuts as the cementing agent. These aggregates constitute roughly 64% of the concrete's total weight. The third layer comprises braised earth, around 150mm thick, topped by a fourth layer of rammed earth, about 100mm thick. In contrast, F-405 starts with a slurry finish of about 2mm thickness, followed by a concrete layer of about 150mm thickness with similar material composition to that of F-901, where the aggregates account for approximately 66% of the concrete's weight. The subsequent layers include braised earth, approximately 70mm thick, and a final layer of rammed earth, around 80mm thick. Visual depictions of these materials are presented in Fig.3 and Fig.4. Remarkably, after more than 5,000 years, the floors of houses F-901 and F-405 maintain a compressive strength akin to that of modern cement mortar with a strength of 10 MPa. In a certain sense, the presence of artificially modified cementitious materials, whether utilized intentionally or unintentionally, in the ground materials of early Yangshao sites substantiates the classification of this as the earliest form of cement in China, termed Yangshao cement.

Fig.3. Calcium nodules[26].

Fig.4. Burnt calcium nodules[26].

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II. PERFORMANCE OF YANGSHAO LIGHTWEIGHT CONCRETE

A. Raw Materials

Originally, the Gansu Provincial Museum Cultural Relics Working Team hypothesized that the floor material of F-405 comprised calcareous materials, fine sand, and natural stone[28] (as depicted in Fig.5). To accurately determine the composition of the ground materials at the Dadiwan site, Li Zuixiong undertook simulation experiments at the Tokyo Institute of Technology during 1985 and 1988[24]. These experiments disclosed that a substantial quantity of calcined ginger nuts powder was used in the construction of the floors at Yangshao sites F-901 and F-405. This material, illustrated in Fig.6, represents a cementitious composite mixed with a minor proportion of red clay. From these findings, it is posited that the principal raw material for Yangshao cement is calcined ginger nuts[30,31]. Additionally, Zhao Linyiperformed a detailed chemical analysis and comparison of the cementing materials found in the ground of F-405, involving calcium nodules, ginger nuts, red clay, and other local materials, as detailed in Table 1[32].

Fig.5. Natural ginger nut[37].

Fig.6. Calcined ginger nut powder[37].

Drawing upon the insights and experimental findings of various researchers, it is evident that the ground materials from the Dadiwan site, specifically F-405, are not simply natural ginger nuts but rather consist of calcined ginger nuts that has undergone high-temperature roasting. Under elevated temperatures, these raw materials experience significant physical and chemical transformations that enhance their cementing properties. The ratio of CaO to SiO_2 in the calcined materials from the Dadiwan site differs markedly from that found in modern cement. In contemporary cement, the CaO content typically exceeds 60%, while the SiO_2 content is approximately 20%. The construction of the F-405 ground is not reliant on a single material; instead, it is a composite that includes calcined gravel powder and red clay. The incorporation of this composite material improves the performance of the ground, resulting in superior construction outcomes. Furthermore, all studies highlight the necessity of processing the ground materials under high-temperature conditions, emphasizing its significance in enhancing both

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

the cementing performance and the overall structural stability of the materials. This approach is analogous to modern cement production techniques, illustrating the ingenuity and technological sophistication of early humans in the domain of building materials.

TABLE 1. CHEMICAL FULL ANALYSIS OF GROUND MATERIALS[32] (%).

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	MnO	CO_2	H_2O^+	SO_3	H_2O^-
Calcium burning nodules	20.50	4.34	1.12	0.50	39.26	1.18	0.70	0.89	0.08	0.25	0.07	30.19	0.62	0.09	0.18
Cementitious material	30.87	6.07	1.96	0.80	31.63	1.74	0.90	1.24	0.13	0.34	0.08	21.61	2.32	0.11	0.80
Ginger nut	22.06	5.44	1.03	0.80	36.82	1.49	0.60	0.98	0.10	0.25	0.08	28.40	1.74	0.10	0.38
Calcium nodules	8.16	0.94	0.80	0.41	49.08	0.60	0.75	0.39	0.02	0.08	0.05	34.04	1.80	0.20	2.28
red clay	62.15	15.79	5.70	0.75	1.06	3.22	1.14	3.08	0.09	0.77	0.09	0.57	5.26	0.07	2.88

B. Mineral Composition

To elucidate the structural and compositional characteristics of the ground materials at sites F901 and F405, various scholars have conducted experimental studies. Zhao Linyi utilized polarized light microscopy to investigate the calcined calcium nodules and cementing materials embedded within the ground of the site[32]. Concurrently, a comparative analysis using polarized light microscopy petrographic images was conducted on ginger nuts and calcium nodules extracted from the surrounding loess near the Dadiwan site. These experiments revealed that calcite is the predominant component of ginger nuts, with an average particle size of approximately 0.005 mm. Conversely, debris primarily consists of quartz, which exhibits a particle size of about 0.035 mm, along with lesser quantities of biotite, muscovite, and iron oxide. The calcined calcium nodules identified in the site's ground are mainly composed of calcite, forming aggregates with particle sizes ranging from microgranular to 0.007 mm. These particles exhibit similar grain sizes and tend to cluster together. The primary constituents of the cementing material in the ground include calcite, augmented by traces of iron oxide, with particles exhibiting an oval shape and varying sizes. Additionally, the debris is chiefly composed of quartz, with particle sizes ranging from 0.014 to 0.035 mm, and contains minor amounts of feldspar and mica, displaying poor mineral development.

Further analysis using X-ray diffraction was performed by Li Zuixiong, who examined the diffraction spectrum of the cementing materials found at the Dadiwan archaeological site[23]. The analysis highlighted a low concentration of hydrated calcium silicate and demonstrated poor crystallization, which was not distinctly observable within the diffraction pattern (Fig.7). The results indicate that the principal mineral components of the calcined nodules at sites F901 and F405 are predominantly calcite and quartz. In the ground cementing materials at site F405, the dominant constituents include calcite, a minor proportion of quartz, trace amounts of feldspar, amphibole, and a limited presence of hydrated calcium silicate.

Chen Ruiyun's research utilized the same X-ray diffraction technique, comparing the diffraction patterns of the cemented material, ginger nut, and loess samples, which were nearly

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

identical, albeit with a few peaks showing variations in intensity[36] (Fig.8). This analysis revealed the presence of minerals such as calcite, quartz, feldspar, and muscovite across all samples, with kaolinite additionally detected in the ginger nut. The cemented material, however, exhibited higher quantities of quartz, feldspar, and dolomite, alongside calcite. Notably, minerals such as $Ca(OH)_2$, C-S-H, CAH, AH, C_2S, C_3S, and C_2AS were not detected.

Previous scholarly research has established that the predominant constituents of the ground materials at the F405 site are calcite and quartz, complemented by minor amounts of feldspar and muscovite. These materials have undergone high-temperature treatment, which has imparted to them distinct physical and chemical properties. Notably, the treated materials exhibit a finer particle size and enhanced cementitious properties compared to natural ginger nuts.

While the site materials exhibit certain characteristics reminiscent of ancient cementitious materials, the key hydration product, such as calcium silicate hydrate, which is pivotal in the hydration process of modern cement, has not been detected in significant quantities. This absence suggests a fundamental difference in the manufacturing processes and mechanisms between the ancient materials and contemporary cement. Furthermore, the low content and poor crystallinity of calcium silicate hydrate in the Dadiwan site's binding materials, in contrast to the stronger crystallinity of the SiO_2 and $CaCO_3$ components, diverge markedly from the higher crystallinity and more pronounced diffraction peaks typically observed in modern cement. Overall, the study reveals the complexity of ancient building material formulation and the unique techniques and processes involved in their high-temperature treatment and material selection, showcasing the advanced technological capabilities of the period and offering valuable insights for modern materials science research.

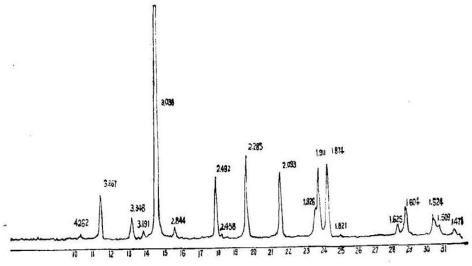

Fig.7. X-ray diffractogram of cemented material[23].

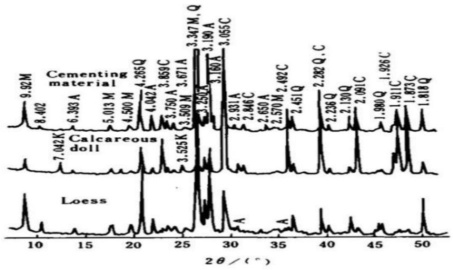

Fig.8. Comparison of X-diffraction of cemented material, ginger nut and loess[36].

C. Physical Properties

Experimental determinations of the bulk density and porosity of burnt granular hollow calcium nodules from sites F901 and F405, as well as the ground material from F405, were conducted by Li Zuixiong and Li Li[26,37]. These properties were compared to those of local limestone, ginger nut, modern man-made clay pellets, and modern lightweight concrete. The findings indicated that the concrete used at the Dadiwan site, which utilized artificially fired calcium nodules as aggregate and calcined ginger nut cement as a binder, demonstrated a bulk density of 1.74 g/cm^3 and a porosity of approximately 27%. This configuration qualifies it as lightweight concrete according to established standards (as detailed in Table 2).

In the context of modern architecture, where the self-weight of concrete significantly contributes to the overall structural load in high-rise buildings, the reduction of concrete's weight is paramount. This type of cement-based lightweight concrete from the Yangshao culture, distinguished by its low bulk density and high porosity, exhibits a lower apparent density and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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reduced self-weight in comparison to modern lightweight concrete. It displays significant lightweight properties when compared with unprocessed natural ginger and limestone. In ancient construction, this material likely reduced the structural load while enhancing moisture resistance and thermal insulation. The presence of numerous closed pores suggests that this ancient concrete may have offered superior performance in certain applications. Nonetheless, modern lightweight concrete often incorporates chemical additives to optimize its overall properties, making it potentially more suitable for contemporary construction needs. The findings indicate that technological advancements in construction materials were already present in the Yangshao culture over 5000 years ago. Although the methods and processes of ancient and modern technologies differ, both have effectively addressed the architectural challenges of their respective periods. This legacy of innovation in material science warrants further investigation into the evolution of ancient construction materials.

Table 2 Analyses of the bulk weight and porosity of materials from the Dadiwan site[26,37].

Sample	Calcium burning nodules (F901、F405)	Ginger nut	Calcium nodules	Light concrete (F405)	Artificial clay ceramsite (Hyundai Beijing)	Lightweight concrete (modern)	Limestone
volumetric weight (g/cm^3)	1.68	2.41	1.14	1.74	1.2	0.7～1.9	2.63
porosity (%)	33	5	46.3	27	45	/	5

D. Microscopic Appearance

Scanning electron microscopy (SEM) was employed by Zhao Linyi to examine the burnt calcium nodules in the ground of F901 and F405, as well as the cementing material in the ground of F405. Comparative analyses were conducted between these SEM images and those of ginger nut (Fig.9) and calcium nodules (Fig.10) found within the Dadiwan region.

SEM observations indicated that the burnt calcium nodules in the grounds of F901 and F405 display underdeveloped mineral structure, rendering hydration crystals virtually invisible under the scanning electron microscope. In contrast, the cementitious material present in the ground of F405 shows more advanced mineral development. The hydrated calcium silicate crystals are distinctly visible under SEM, accompanied by a minor presence of dendritic hydrated tricalcium aluminate ($3CaO \cdot Al_2O \cdot nH_2O$)[26,38] (Fig.11).

Based on the analysis, the development of burnt lime nodule minerals in the F901 and F405 floor samples is relatively poor. This indicates that the early manufacturing processes may have been affected by non-uniform temperature control or inadequate heat treatment duration, resulting in less well-developed mineral structures within the burnt lime nodules. In contrast, the mineral development in the binding materials of the F405 floor is more complete, suggesting a more advanced technical understanding of cementing material preparation by the Yangshao culture. Furthermore, the results of scanning electron microscopy and X-ray diffraction reveal the presence of hydrated calcium silicate crystals and a small amount of dendritic hydrated calcium aluminate. These findings indicate that the material underwent hydration reactions during its use, leading to the formation of certain hydrated phases that enhanced the strength and stability of the material.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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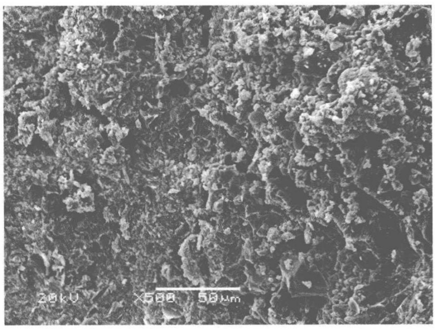


Fig.9. Micrographs of the ginger nut[26].

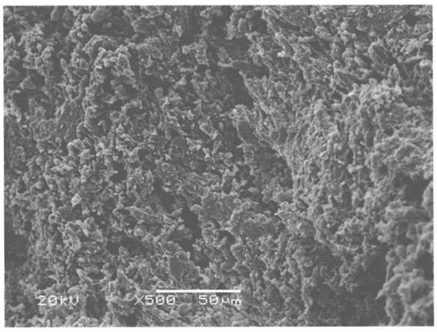
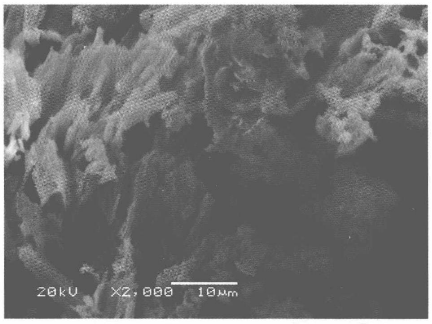
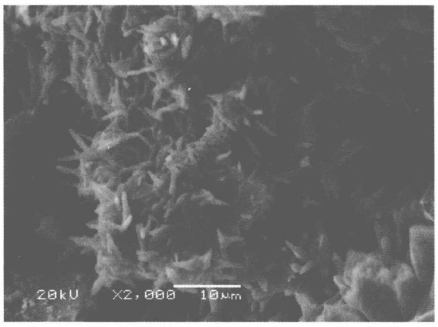


Fig.10. Micrographs of calcium nodules[26].



(a) Micrographs of hydrated calcium silicate.



(b) Hydrated tricalcium aluminate.

Fig.11. Micrographsin F405 ground cementitious material[26].

E. Reaction Mechanism

In the detailed analysis of the chemical product hydro hardness and gas-hardness alteration process following high-temperature calcination of ginger nut, Li Zuixiong has presented a partial reaction equation elucidating the hydration mechanism[39]. The investigation highlights that upon interaction with water, calcined ginger nut triggers hydration reactions in β-type calcium silicate and dicalcium aluminosilicate, leading to the development of hydrated calcium silicate and hydrated dicalcium aluminosilicate, respectively:

$$CaCO_3 + Clay \xrightarrow{900℃} 2CaO \cdot SiO_2(C_2S) \quad (1)$$

$$2CaO \cdot SiO_2(C_2S) \xrightarrow{H_2O} 2CaO \cdot SiO_2 \cdot nH_2O(C_2SH_n) \quad (2)$$

$$2CaO \cdot SiO_2 \cdot nH_2O(C_2SH_n) \xrightarrow{CO_2 \cdot H_2O} CaCO_3 + H_2O \quad (3)$$

At the same time, the calcium oxide in the calcined ginger nut reacts with water to form quicklime, which subsequently undergoes a slow reaction with atmospheric carbon dioxide, ultimately yielding calcium carbonate:

$$Ca(OH)_2 \xrightarrow{CO_2} CaCO_3 + H_2O \quad (4)$$

This porous calcium carbonate exhibits excellent permeability and breathability, coupled with suitable strength. Through a compilation of previous literature, Li Li supplemented the reaction process of continued hardening of hydrated lime: a portion of the hydrated lime formed after ground construction, along with added clay, reacts to produce well-bonded amorphous calcium silicate hydrate[26]. The resulting binder possesses high mechanical strength:

$$1.5Ca(OH)_2 + SiO_2 \xrightarrow{H_2O} 1.5CaO \cdot SiO_2 \cdot nH_2O(C_2SH_n) \quad (5)$$

$$1.5CaO \cdot SiO_2 \cdot nH_2O(C_2SH_n) \xrightarrow{CO_2 \cdot H_2O} CaCO_3 + H_2O \quad (6)$$

This is the reason why hydraulic lime restoration and reinforcement of stone cultural relics have proven to be effective in protection and reinforcement. Zhao Linyi further adds that the strength of the $CaCO_3$ gelling substance, which is formed through rapid surface carbonation, complements the rapid hydration of

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the water-hardened component, resulting in the production of β-$CaSiO_3 \cdot nH_2O$ and $Ca_2Al_2Si_2O_8 \cdot nH_2O$ within the stone body. This combination adequately fulfills the requirements for cultural relics restoration[34].

Research has demonstrated that the hydration reaction of high-temperature calcined aggregates is a complex, multi-step, multi-phase process involving both hydraulic and non-hydraulic reactions. This process encompasses interactions among various minerals and includes not only the hydration of primary reactants but also the effects of secondary reactions such as the presence of impurities, reaction temperature, and the chemical properties of water. The presence of a significant proportion of aluminum minerals (e.g., bauxite) enhances the formation of calcium aluminate hydrate, thereby improving the strength and stability of the final product. Consequently, examining the hydration rates and characteristics of different minerals is essential for optimizing Yangshao cement formulations. Additionally, while performing hydration at elevated temperatures can accelerate the reaction, it may also induce precipitation or structural changes in certain hydration products. Therefore, optimizing reaction conditions is also crucial for enhancing the final performance of Yangshao cement-based concrete materials.

F. Age Identification

Scholars have pointed out that the process of absorbing carbon dioxide by fired lime, which contains radioactive carbon-14, allows for the use of ground building materials containing calcium carbonate as carbon-14 specimens for dating purposes, akin to those found at archaeological sites[40]. Li Zuixiong conducted carbon-14 dating analyses on the burned lime nodules in the floors of the Qin'an Dadiwan site labeled as F901 and F405, as well as the binding materials in the F405 floor and the sintered stones produced at Dadiwan. These results were compared with those obtained from charcoal specimens (as detailed in Table 3). The dating results revealed that the binding materials in the concrete of the archaeological site's floors and the artificially fired lightweight aggregates date back over 6000 years, corresponding to the Yangshao period of the Neolithic era[24,26,27]. Furthermore, Chen Ruiyun research corroborated that the F405 site dates back more than 5000 years[36].

The measurements conducted by the aforementioned scholars reveal that the inhabitants of the Yangshao period had achieved a high level of technical proficiency in the application of building materials. They were able to utilize local resources for the calcination and processing of raw materials, resulting in the production of high-performance construction materials. The use of ginger nuts and cementing materials indicates that Neolithic people possessed extensive experience and a continuous process of refinement in the selection and manufacturing of building materials.

IV. IMITATION OF YANGSHAO LIGHTWEIGHT CONCRETE

Initially, it was believed that the ground materials discovered in F-901 and F-405 at the Dadiwan site comprised ancient Chinese concrete. However, the cultural importance of these relics poses significant challenges for conducting field explorations or in-situ testing. As a result, scholars have engaged in imitation studies, which focus on exploring the variations in the composition of Yangshao cement raw materials under different calcination temperatures. These studies also extend to examining the mechanical properties of Yangshao lightweight concrete, such as its tensile, compressive, and flexural strengths, along with its triaxial compression characteristics and other relevant properties. These efforts are aimed at not only understanding but also replicating the ancient material's qualities in a controlled environment, contributing to a deeper appreciation and application of historical construction techniques.

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Table 3 Carbon-14 dating of ground materials in Dadiwan F901, F405[27].

Carbon-14 specimens	Specimen number	Age (B.P.)	Calibration Year (B.P.)
F405 Charcoal	BK81049	4410±80	4910±180
F405 Ground cementing material	LB84-91	6769±312	
F901 Charcoal	BK84	4550±100 4750±100	
F405、F901 Calcium burning nodules	LB84-92	6137±159	

A. Firing Temperature

The firing temperatures of pottery sherds from different phases (Phase II, Phase III, Phase IV, and Phase V) at the Dadiwan site were initially determined using a thermal expansion meter by Zhao Linyi. Through these measurements, it was inferred that the ginger nuggets and calcium burning nodules discovered at the site were fired in the same kiln where the pottery was processed, at temperatures ranging from approximately 840 to 1040°C[32].

In further experimentation with ginger nut specimens, it was observed that the chemical products resulting from combustion within the temperature range of 700°C to 1400°C displayed characteristics typical of both water-hardened and air-hardened components. Notably, as the temperature increased, there was an initial rise followed by a reduction in the non-aqueous component, while the aqueous component consistently increased. The chemical composition and properties of these products were found to be similar to those of European "hydraulic lime"[38,40-43].

Li Zuixiong conducted simulated firing experiments on natural ginger nuts to analyze the chemical products formed at different temperatures. The results of these experiments, including XRD diffraction patterns and semi-quantitative analyses, are presented in Fig.12 and Table 4. These experiments demonstrated that the roasting temperature directly affects the proportion of water-hardened and air-hardened cementitious materials in the product. The raw ginger nuts primarily consist of calcium carbonate, SiO_2, and minor amounts of feldspar and clay. At temperatures exceeding 800°C, the calcium carbonate in the ginger nuts decomposes completely into calcium oxide. Subsequent chemical interactions between calcium oxide and SiO_2, feldspars, and oxides in the clay lead to the formation of β-type calcium silicate and dicalcium aluminosilicate[39,43].

Zhao Linyi's calcination experiments on natural ginger nut material further explored changes in product composition across different temperatures. The findings revealed that:

The production rate of CaO significantly increased within the temperature range of 800 to 1100°C, peaking at 42.1wt%. This range was identified as optimal for CaO production. Conversely, there was no significant increase in the production of β-$CaSiO_3$, which stabilized around 24.7wt%, only slightly rising to 28.4wt%. The growth of $Ca_2Al_2Si_2O_8$ was minimal, increasing from 16.3wt% to 19.1wt%.

During the roasting process at 1100 to 1400°C, the amount of CaO sharply decreased from 42.1wt% to 16.7wt%, primarily due to the gradual depletion of CaO. The production rates for β-$CaSiO_3$ and $Ca_2Al_2Si_2O_8$ significantly increased, with β-$CaSiO_3$ rising from 28.4wt% to 47.7wt% and $Ca_2Al_2Si_2O_8$ from 19.1wt% to 35.5wt%[32] (as depicted in Fig.13).

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ISSN: 2278-0181
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Table 4 Results of semi-quantitative XRD analyses of burnt ginger nuts from Dadiwan[39].

Sample number (condition)	Semiquantitative analysis results (%)							
	SiO_2	calcium carbonate	calcium oxide	calcium hydroxide	β-type calcium silicate	Dicalcium aluminosilicate	feldspar	clay
D-S-0 Unburnt samples	12.7	79.8	/	/	/	/	4.4	3
D-S-1 700℃-3h	16.4	77.2	/	/	/	/	4.4	2
D-S-2 800℃-3h	6.1	/	33.5	5.7	52.6	/	/	2
D-S-4 900℃-3h	3.3	/	32	4.1	52.3	6.2	/	2
D-S-7 1000℃-3h	1	/	26.6	5.9	55.7	8.7	/	2
D-S-8 1100℃-3h	1.0	/	27.7	/	54.4	13.6	1.2	2
D-S-10 1200℃-3h	/	/	19.3	9.7	47.3	22	1.7	/
D-S-13 1300℃-3h	/	/	11.3	/	62.7	23.5	/	2
D-S-14 1400℃-3h	/	/	9.3	11.9	47.2	30	1. 6	/

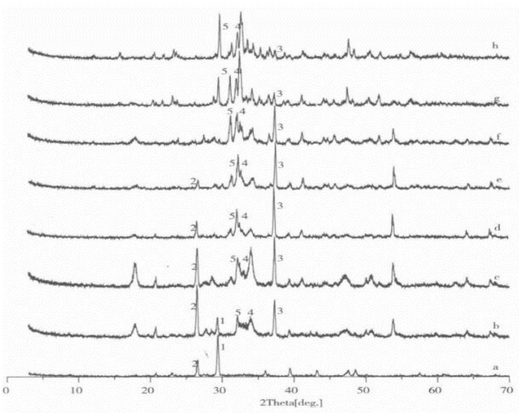

Fig.12. X-ray diffraction spectra of calcined ginger nut from 700°C to 1400°C and comparison of the products[39]. (Main diffraction peaks: 1. Calcium carbonate; 2. Silicon dioxide; 3. Calcium oxide; 4. β-type calcium silicate; 5. Dicalcium aluminosilicate)

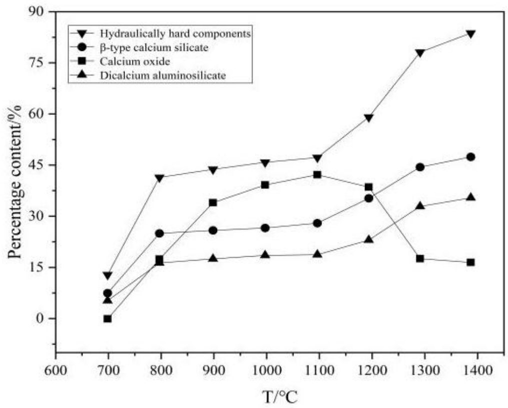

Fig.13. Trend of the main products of the ginger nuts after roasting at 700°C ~ 1400°C for 3 hours[32].

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B. Firing Process

The firing process of Yangshao cement is primarily characterized by the treatment of natural ginger nut through controlled indoor experiments. This process begins with the initial crushing of the ginger nut, followed by roasting at various temperatures, including 700°C, 800°C, 900°C, 1000°C, 1100°C, 1200°C, 1300°C, and 1400°C, each for a duration of three hours. After roasting, the material is ground in a ball mill until it achieves a particle size finer than a 200-mesh sieve, ensuring a high level of fineness[35].

To identify the gel materials used on the site's floor, Li Zuixiong conducted analyses using a polarizing microscope and X-ray diffraction. These techniques were employed to compare the gel materials with the mineral composition of natural sintered stone, providing insights into the materials' structural and compositional similarities. Through this comparative analysis, the production process of the Yangshao lightweight concrete used on the F405 floor was elucidated. The process involves the initial calcination of sintered stones, followed by their crushing. The crushed material is then mixed with approximately 10-20% red clay, which acts as a binder. This mixture is finally combined with fired lime nodules, serving as artificial lightweight aggregates, to create the lightweight concrete[24].

In summary, the firing process of Yangshao cement, as described by the aforementioned scholars, includes several key steps: crushing the natural ginger nut, mixing it with a small amount of clay, calcining it at high temperatures, grinding it into a fine powder, and sieving the resulting material. The current body of research indicates that during the calcination process at temperatures between 700°C and 1400°C, selecting an optimal temperature is critical for the formation and performance of mineral phases. The reactivity of these mineral phases exhibits significant variation across different temperatures. As such, a gradient firing technique, wherein the temperature is progressively increased at different stages, could be employed to ensure that the minerals undergo complete reactions. This method not only reduces energy consumption but also enhances the quality of the cement by achieving optimal reactivity and preventing the degradation of material properties due to excessive sintering. While existing experiments have standardized the calcination duration at 3 hours, comparative studies varying the duration could identify the optimal calcination time. Adjusting the calcination time—whether by extension or reduction—may improve the properties of the cement, such as increasing its strength and reducing porosity. Moreover, the organic matter and trace elements (e.g., aluminum, iron) present in the incorporated red clay could affect the color and other characteristics of the cement. Therefore, these factors should be carefully considered in the selection of raw materials.

C. Mechanical Properties

1) Compression and Flexural Strength

To comprehensively analyze the compressive and flexural properties of Yangshao cement, SL-labeled specimens were prepared by Li Li, Zhao Linyi, and Wang Jinhua[26,43-45]. These specimens were composed of a 1:1 mass ratio of sintered ginger nuts to quartz sand, with a water-to-cement ratio of 0.33. The dimensions of the specimens were 40mm×40mm×160mm. Their compressive and flexural strengths were evaluated at intervals of 3, 7, 14, and 28 days. Experimental findings indicated a rapid increase in compressive strength for the SL-labeled specimens over the respective curing periods, with compressive strength increases of 0.94, 1.29, and 3.09 MPa respectively. Similarly, the flexural strength of these specimens also demonstrated significant improvements within the 28-day period. Under the same curing conditions, the flexural strength reached 1.03

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MPa at 3 days, representing 93.6% of the strength observed at 28 days. These results indicate that SL specimens, the test pieces under this ratio, exhibited high early flexural strength with marginal increases at subsequent intervals, followed by a slight decline at 28 days (as depicted in Fig.14).

Additionally, under identical conditions, the unconfined compressive strength of the stone specimens reached 2.45 MPa at 3 days, with a notable increase observed over the next three intervals. The specimens demonstrated exceptional early strength, robust flexural strength, and enhanced unconfined compressive strength (as depicted in Fig.15).

Drawing upon the experimental data provided in the scholarly literature, the reasons for the high compressive and flexural strengths of the SL specimen can be analyzed as follows: The high-temperature calcination of the ginger nuts leads to the formation of highly reactive mineral phases such as calcium silicate and calcium aluminate silicate. These reactive mineral components produce gel phases, including calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate (C-A-S-H), during the hydration process, which possess excellent cementitious properties. The hydration reactions release substantial heat in the early stages, further accelerating the hardening process of the cement matrix. The dense microstructure formed by these gel phases within the cement matrix significantly enhances the compressive and flexural strengths of the material. Furthermore, the inclusion of quartz sand as an inert aggregate provides stable volumetric support and a robust skeletal structure, which mitigates material shrinkage and deformation while limiting crack propagation. The synergy between quartz sand and the reactive mineral phases reinforces the overall structural stability, allowing the material to exhibit high strength during both early and later stages of development. Additionally, the relatively low water-to-cement ratio of 0.33 contributes to reducing excess water evaporation and pore formation during hydration, thereby improving the material's density and strength. This low water-to-cement ratio is advantageous for the rapid development of early strength and the maintenance of high strength in the later stages.

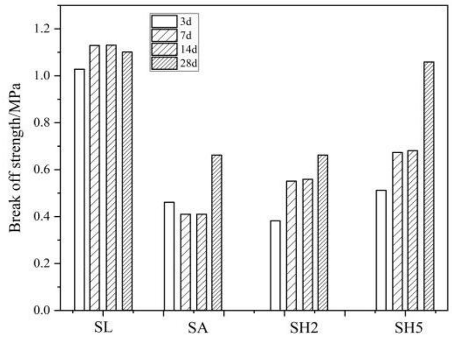

Fig.14. Age variation of flexural strength of simul ated fired specimens[26].

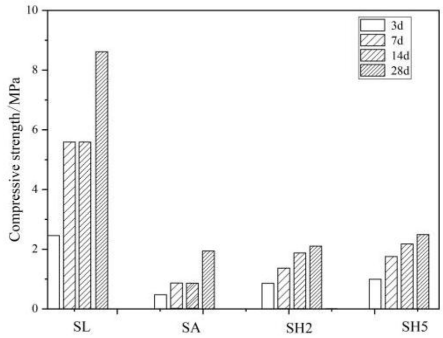

Fig.15. Age variation of compressive strength of simulated fired specimens[26].

2) Tensile Strength

For tensile strength analysis, Chen Weichang selected ginger nuts that had been roasted at 1000°C for 3 hours and then ground into a powder with a particle size of 0.08 mm. Specimens were prepared using a mass ratio of 1:1 for quartz sand to calcined ginger nuts, with a water-cement ratio of 0.33. The Brazilian split test specimens, measuring 50 mm in diameter and 25 mm in height, exhibited an average tensile strength of 2.072 MPa. The tensile-to-compression ratio calculated for these specimens was 7.40, indicating improved ductility and a higher capacity to withstand tensile deformations[37] (as depicted in Fig.16).

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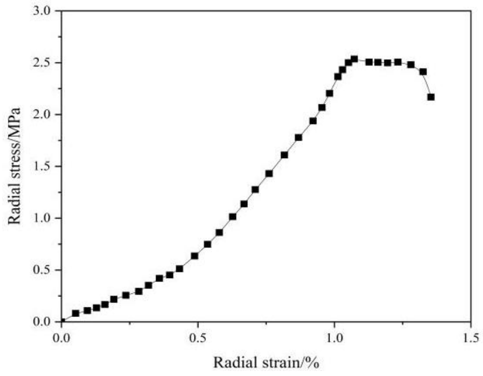

Fig.16. Brazilian splitting stress-strain curves for specimens[37].

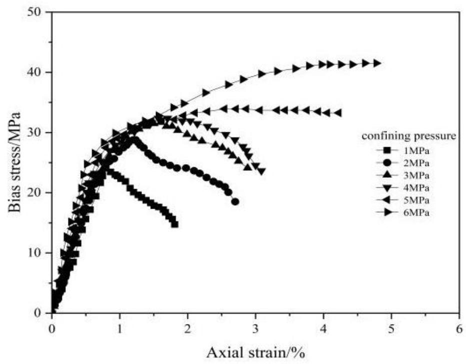

Fig.17. Triaxial compression curves of stress-strain of specimens under different circumferential pressures[37].

3) Triaxial Compression Characteristics

Chen Weichang also conducted experiments to evaluate the triaxial compression characteristics of mixtures of calcined ginger nut and quartz sand. These experiments used the same specimens as those in the tensile strength tests. The stress-strain curves under triaxial compression conditions exhibited a less pronounced compression-density phase compared to uniaxial compression conditions. During the elastic deformation stage, the stress-strain relationship was primarily linear, with the elastic modulus observed to increase with rising confining pressure. The plastic deformation stage showed prolonged behavior, with axial stress and strain increasing gradually, akin to the flow behavior of soft rock. In the failure stage, even under low confining pressures, the specimens exceeded peak strength but maintained significant bearing capacity. Notably, at a confining pressure of 5 MPa, the specimens retained a robust bearing capacity. However, at 6 MPa, no shear failure occurred; instead, the specimens demonstrated plastic flow, with the peak strength approaching ideal plasticity[37] (as depicted in Fig.17).

V.MODIFICATION OF YANGSHAO LIGHTWEIGHT CONCRETE

Yangshao cement, a water-hardening cementitious material, is primarily composed of calcined ginger nut powder and a minor propo rtion of red clay. This material functions as an alkali cementitious substance and exhibits properties superior to those of ordinary silicate cement, including enhanced refractoriness, resistance to carbonation, sulphate corrosion, acid and alkali corrosion, long-term strength, freeze-thaw resistance, and thermal stability. Despite these attributes, further research is necessary to adapt Yangshao lightweight concrete for reinforcing and safeguarding cultural relics under diverse environmental conditions.

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Numerous scholars have sought to improve its porosity, reduce shrinkage and deformation, and enhance water stability and freeze-thaw resistance through various modifications, yielding significant advancements.

A. Modification with Metakaolin

Fissure grouting reinforcement technology is a prevalent method for site protection. This technique involves injecting grouting materials into existing fissures, where the grout consolidates with the surrounding soil to fill gaps and unify loose particles into a cohesive structure. This process effectively impedes rainwater infiltration, preventing the expansion of fissures and enhancing the site's durability. The heightened reactivity of metakaolin allows it to react with calcium oxide in hydraulic lime to form dicalcium aluminosilicate, a crucial chemical component in cement. This compound can undergo further hydration to produce hydrated dicalcium aluminosilicate, commonly referred to as cement stone. The presence of cement stone significantly increases the strength of the grouted stone body over time, offering substantial benefits in seepage prevention[48,54].

Experimental studies utilized calcined ginger nut water-hard lime as the primary component. Various proportions of metakaolin and quartz sand were blended with the lime, adjusting the water-cement ratio to prepare the slurry. Experiments assessed the slurry's fluidity and setting time, alongside the strength of the stone body at different ages, and the contraction and deformation at 28 days. From these data, the optimal ratio of hydraulic lime, metakaolin, and quartz sand was established as 1:0.6:0.4. The inclusion of metakaolin markedly improved the age strength of the slurry stone body, particularly its early strength. Further investigations varied the water-cement ratio to examine the effects on fluidity, setting time, strength at different ages, and 28-day shrinkage and deformation. Results indicated that for grouting rock fissures, a water-cement ratio between 0.60 and 0.70 is suitable, while for restoring rock surfaces and repairing stone artifacts after grouting, a water-cement ratio between 0.40 and 0.50 is recommended[54].

B. Modification with Fly Ash

In continuation of the modification studies involving metakaolin, further research has been conducted using calcined ginger nut water-hardened lime (CGN) as the base material, incorporating fly ash (F) as a mixing component to enhance the properties of the concrete. The resultant composite, referred to as serous stone bodies, utilizes CGN as the foundational material and fly ash as the mixing element.

Studies on anchoring slurries for soil stabilization were carried out under simulated indoor curing conditions, using quartz sand, fly ash, and calcined ginger nut as the primary components. These investigations demonstrated that the calcined ginger nut-fly ash slurry (CGN-F) offers excellent resistance to temperature and humidity fluctuations, alkaline environments, and sulfate erosion. Moreover, the combination of burnt concretion-fly ash with quartz sand in the slurry (CGN-FS) showed enhanced compatibility with soil sites. This slurry proved to be particularly effective for anchoring in soil site protection, owing to its superior compatibility and durability[33,46].

Additionally, outdoor soil curing experiments were conducted to evaluate the performance of various admixture ratios involving calcined ginger nut water-hardened lime, fly ash, and quartz sand under fixed mobility conditions. Results from these tests indicated that the anchoring slurry composed of calcined ginger nut and quartz sand, in a mass ratio of 1:1, exhibited optimal performance[47]. This suggests that the inclusion of fly ash not only enhances the environmental resilience of the composite but also improves its mechanical properties, making it an effective choice for applications in soil stabilization and site protection.

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VI. ENGINEERING APPLICATIONS AND DEVELOPMENT TRENDS

A. Practice in the Protection of Ancient Buildings and Cultural Relics

Yangshao lightweight concrete, characterized by its excellent compressive and flexural strength, lightweight properties, good stability, and high durability, also demonstrates remarkable compatibility with cultural relics and historical artifacts. This compatibility is crucial in preserving the original state of these items, ensuring the authenticity and integrity of their physical structures. Consequently, Yangshao lightweight concrete is suitably applied in the protection and restoration of ancient buildings and cultural relics.

A prevalent technique for reinforcing and protecting earthen ruins is anchoring, which involves the use of various types and materials of anchors to strengthen cracked soil. This method is increasingly recognized as a vital approach to manage cracking in earth sites [48]. Research involving a grout made from water-hardened lime derived from burnt ginger nut mixed with soil from the Hongshabao site at the same mass ratio examined its aging performance. Results indicated that at 28 days, parameters such as shrinkage, water content, and elastic wave velocity tended to stabilize, while strength indicators tended to stabilize at 90 days. The permeability coefficient and density were found to resemble those of the site soil, confirming the slurry's suitability as an anchoring grout[49].

Additionally, the use of calcined ginger nut as the base material for grouting, mixed with soil from the Xiaguanying site, has led to the development of grouting materials that demonstrate stable structure, good integrity, and strong resistance to rain erosion, thus proving to be suitable for soil site applications[50].

In recent years, the application of water-hardened lime derived from burnt ginger nut in grotto fracture grouting has seen notable success. Modified Yangshao cement has become a crucial material for sandstone grotto fissure grouting. In 2015, research by Zhao Linyi[35] and their team focused on "Yangshao cement" and its compatibility with sandstone grottoes, specifically examining its characteristics in fissure reinforcement. This study successfully identified suitable grouting materials and ratios for reinforcing sandstone grotto fissures, effectively addressing the challenges of material selection for grotto grouting.

Further, Li Li and their team compared China's traditional hydraulic lime with the European hydraulic lime that has been successfully applied in cultural relics restoration. Their study adjusted the composition of China’s traditional hydraulic lime to effectively match the characteristics of cultural relics, thereby enhancing its suitability for various restoration projects. These modified materials have been successfully used in the protection and restoration of diverse sites such as the underground palace of Nanjing's Jien'en Temple, the stone cultural relics of Chengde's Anyuan Temple and Puren Temple, and the site of Inner Mongolia's Yuan Shangdu, addressing the need for suitable materials in China’s arid environments[51-54].

Moreover, modified lightweight concrete utilizing Yangshao cement has been employed in the preservation of geotechnical cultural relics, including the restoration of mural floor battles in tomb chambers and the reinforcement of mural paintings in humid environments. In 2004, a systematic study by Ma Qinglin explored the use of calcined ginger nut for repairing and reinforcing the plaster of ancient tomb paintings in humid conditions, demonstrating successful applications in this field[55].

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B. Development Trend

China's extensive distribution of rock-soil cultural relics constitutes a vital component of the nation's cultural heritage. The development and utilization of traditional cementitious materials hold substantial promise. Current research on Yangshao cement-based lightweight concrete indicates certain limitations, highlighting the need for future theoretical investigations aimed at optimizing Yangshao cement formulations. This includes in-depth studies on mineral hydration rates and product characteristics. Improving reaction conditions could significantly enhance the performance of Yangshao cement-based concrete materials. Exploring different calcination durations could pinpoint the optimal firing times, while considerations of organic compounds and trace elements (e.g., aluminum, iron) in raw materials such as red clay from various aggregate sources are essential. Furthermore, ongoing research into additional concrete admixtures is crucial for evaluating the physical and mechanical properties of modified Yangshao cement lightweight concrete. Emphasis should be placed on integrating diverse materials and technologies effectively to maximize strengths and mitigate weaknesses, ensuring superior compatibility, water stability, and durability with rock-soil cultural relics.

With the rapid advancements in smart construction and digital technologies, Yangshao cement, as a traditional building material, is poised to explore new avenues for development. The integration of cutting-edge sensors and data analytics enables the intelligent monitoring and management of Yangshao cement production processes. Concurrently, technologies such as Building Information Modeling (BIM) enhance digital collaboration and optimize construction processes. Moreover, the application of Augmented Reality (AR) enhances operational precision and quality control on construction sites. Through the use of big data analytics to refine production processes, Yangshao cement can progress towards more environmentally sustainable practices, thereby presenting innovative strategies and pathways for the intelligent transformation of the construction industry. In the context of the "dual carbon" goals, future engineering practices must prioritize green, low-carbon. This may involve utilizing industrial solid waste-derived aggregates and mineral admixtures that uphold concrete performance standards, alongside exploring potential carbon sequestration materials. Ultimately, as a traditional building material in ancient China, Yangshao cement-based lightweight concrete is poised to integrate across various domains, making substantial contributions to architectural design and the preservation of cultural heritage nationwide.

VII.CONCLUSIONS

Yangshao lightweight concrete, one of the earliest materials discovered and applied in the field of traditional Chinese materials, demonstrates superior properties in certain aspects compared to modern concrete. This paper has provided a comprehensive overview of the discovery history, raw material composition, mineral composition, reaction mechanism, replication techniques, physical and mechanical properties, modification research, and engineering applications of Yangshao lightweight concrete, drawing from both domestic and international research findings. The key conclusions from this research are as follows:

(1) Historical and Architectural Significance: At the Dadiwan site in Qin'an County, Tianshui City, Gansu Province, two significant dwellings, F-901 and F-405, were identified where the oldest concrete in China, Yangshao lightweight concrete, was discovered on the floors.

(2) Material Composition: Analysis of the chemical and mineralogical composition of the ground material from these sites indicated that

the primary raw materials were locally sourced calcined ginger nuts, burnt calcium nodules, and red clay. Scanning electron microscopy and X-ray diffraction analyses confirmed significant amounts of calcite and minor hydration products of calcium silicate.

(3) Physical Characteristics: The concrete utilized artificially fired calcium nodules as aggregates and calcined ginger nut cement as the binder, featuring a bulk density of 1.74 g/cm³ and approximately 27% porosity, classifying it as lightweight concrete due to its low bulk density and high porosity.

(4) Reaction Mechanism: The hydration reactions of β-type calcium silicate and dicalcium aluminosilicate upon interaction with water lead to the formation of hydrated calcium silicate and hydrated dicalcium aluminosilicate. These reactions, along with air-hardening processes, enhance the material's strength, making it suitable for the restoration and reinforcement of cultural relics.

(5) Firing Temperatures: The analysis of firing temperatures of ceramic fragments from the Dadiwan site suggested that the ginger nut and calcium nodules were fired in kilns alongside ceramics at temperatures ranging from 840 to 1,040 degrees Celsius. The simulation of ginger nut firing revealed dual characteristics of water-hardening and air-hardening, with changes in component proportions varying with temperature.

(6) Mechanical Properties: Indoor mechanical experiments on simulated Yangshao lightweight concrete revealed an average tensile strength of 2.072 MPa at 3 days. The material exhibited substantial flexural strength and unconfined compressive strength, demonstrating significant load-bearing capacity even under high peripheral pressures during triaxial compression conditions.

(7) Applications and Future Potential: Enhanced with metakaolin, quartz sand, fly ash, and other additives, Yangshao lightweight concrete is suitable for applications such as earth site reinforcement, grotto crack grouting, and battle damage restoration. It presents environmentally friendly characteristics, exceptional durability, and cost-effectiveness, making it a promising option for urban infrastructure development. Additionally, the historical significance of Yangshao lightweight concrete extends beyond its early contributions to human civilization and lays a foundational role in the development of modern building materials and the preservation of ancient cultural relics in China, fostering a unique “Yangshao culture” with vast potential for future exploration and application.

VII.AVAILABILITY OF DATA AND MATERIALS

All data generated or analysed during this study are included in this published article.

IX. COMPETING INTERESTS

The authors declare that they have no competing interests.

X.FUNDING

This work was supported by the Jiangsu Education Science Planning Project (grant number 2022B16), Key Research Project about Frontier Foundation of Huai’an (grant number HAQ202202), Open fund for Jiangsu Engineering Laboratory of Structure Assembly Technology on Urban and Rural Residence (grant number JSZP201904), and Innovation and Entrepreneurship Training Plan for College Students (grant number 202311049052Y,202311049343YJ).

XI.AUTHOR CONTRIBUTIONS

Conceptualization, Yuyi Liu, Yangguang Li; methodology, Yuyi Liu, Yun Dong; formal analysis, Haigang Zhang, Baoliang Li ,Yongzhen Chen; investigation, Yangguang Li, Haigang Zhang, Jiale Yu; writing—original draft preparation, Yangguang Li, Yuyi Liu; writing—review and editing, Abdoullah Namdar; supervision, Yuyi Liu. All authors have read and agreed to the published version of the manuscript.

XII.ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of Huaiyin Institute of Technology. We would also like to thank the editors and anonymous reviewers for their helpful and productive comments on the manuscript.

[1] Sparavigna A C . Some Notes on Ancient Concrete. International Journal of Sciences. 2014;3(2):1-6.

[2] Kanare H, Milevski I, Khalaily H, Getzov N and Nasvik J. How Old is Concrete. Concrete Construction. January 2009.

[3] Sparavigna A C . Ancient concrete works. Popular Physics. 2011.

[4] Demortier G. Revisiting the Construction of the Egyptian Pyramids. Europhysics News. 2009;40(1):27-31.

[5] Wo A, Lian X. Ancient Egyptian pyramid built with "concrete". Construction workers. 2007;2(07):53.

[6] Allard C . Self-healing Roman concrete. Nature Reviews Materials. 2023;8(80).

[7] Elif S U, Engin H D, Hasan B. Lime mortar technology in ancient eastern Roman provinces. Journal of Archaeological Science: Reports. 2021;39(4):103132.

[8] Swallow P , Carrington D. Limes and lime mortars. Journal of Architectural Conservation. 1995;1(3):7-25.

[9] Bentur A. Cementitious Materials—Nine Millennia and A New Century: Past, Present, and Future. Journal of Materials in Civil Engineering. 2002.

[10] Moropoulou A, Bakolas A, Anagnostopoulou S. Composite materials in ancient structures. Cement & Concrete Composites. 2005;27(2):295-300.

[11] Xu B, Pu X C. Superior durability of ancient concrete and the development prospect of alkali slag cement. Building Materials and Applications. 1997;25(4):23-2522.

[12] Hill D. Ancient Roman Concrete Could Hold Secrets to Improving Modern Construction. Civil Engineering (0885-7024). 2013;83(9):44-45.

[13] Tagnit-Hamou A, Tognonvi M T, Davidenko T, et al. From Ancient to Modern Sustainable Concrete. RILEM Bookseries. 2015;10:75-82.

[14] Heinemann H A. Historic Concrete - From Concrete Repair to Concrete Conservation architecture. 2013.

[15] Yang H. A preliminary study of the house development in the Yangshao culture. Archaeological Journal. 1975;1:39-72.

[16] Zhang X. The discovery and research of Yangshao culture in gansu province. Cultural Relics in Southern China. 2023;4:203-13.

[17] Gansu Provincial Institute of Cultural Relics and Archaeology. Brief report on excavation of early Yangshao culture settlements in Dadiwan Site, Qin 'an County, Gansu Province. Archaeology. 2003;6:20-31.

[18] Gansu Provincial Institute of Cultural Relics and Archaeology. Important archaeological discoveries in Gansu province 2000-2019. Beijing: Cultural Relics Publishing House; 2020. p. 56-77.

[19] Qiu S. When did the artificial burning of lime begin. Archaeology and Cultural Relics. 1980;(3):126-8.

[20] Miao J, Li X, Cheng R. Preliminary study on ancient Chinese cementitious materials. Journal of the Chinese Ceramic Society. 1981;9(2):234-40.

[21] Yang F, Zhang B, Pan C. The traditional mortar represented by glutinous rice mortar is one of the important inventions in ancient China. Science in China Series E: Technical Sciences. 2009:52(6):1641-7.

[22] Gansu Provincial Museum cultural relics work team. The main harvest from 1978 to 1982 excavations at the Dadiwan Site in Qin 'an, Gansu Province. Chinese CulturalRelics. 1983;1:21-30.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

[23] Li Z. Miracles in the history of ancient Chinese architecture. Research on floor building materials and techniques of Yangshao culture houses in Dadiwan, Qin'an. Archeology. 1985;8:741-7.

[24] Li Z. The oldest concrete in the world. Archeology. 1988;8:751-7.

[25] Archaeology M. 100 Major archaeological discoveries in China in the 20th century. Beijing: Social Sciences Press; 2005.

[26] Li L, Zhao L. Study on lime materials in ancient China. Beijing: Cultural Relics Publishing House; 2015.

[27] Li L, Zhao L, Wang J. Study on physical and mechanical properties of two traditional silicate materials used in ancient Chinese architecture. Journal of Rock Mechanics and Engineering. 2011;30(10):2120-7.

[28] Lang S. Brief report on the excavation of Room Site No. 901, Dadiwan, Qin 'an, Gansu Province. Chinese CulturalRelics. 1986;2:1.

[29] Zhao J. Site of No. 405 neolithic house in Dadiwan, Qin 'an. Chinese Cultural Relics. 1983;11:15-21.

[30] Gansu Provincial Institute of Cultural Relics and Archaeology. Dadiwan, Qin 'an: Report on the excavation of neolithic sites. Beijing: Cultural Relics Publishing House; 2006.

[31] Li S. Henan Yangshaocun site found more than 5000 years ago suspected cement concrete. Identification and Appreciation to Cultural Relics. 2021;6:113.

[32] Zhao L. The modification research of two kinds of traditonal materials used on preservation of the stone and earthen cultural relics. Lanzhou University. 2012.

[33] Zhang J, Chen W, Li Z, Wang X, Guo Q, Wang, N. Study on workability and durability of calcined ginger nuts-based grouts used in anchoring conservation of earthen sites. Journal of Cultural Heritage. 2015;16(6):831-7.

[34] Li Z, Zhao L, Li L. Research on new grouting materials for rock fissure in sandy conglomerate grottoes. Dunhuang Research. 2011;6:59-64.

[35] Zhao L, Li L, Li Z. Study on two traditional silicate materials in ancient Chinese architecture. Journal of Inorganic Materials. 2011;25(12):1327-34.

[36] Chen R. A study on the ground building materials of Dadiwan Neolithic Site, Qin 'an County, Gansu Province. Journal of the Chinese Ceramic Society. 1993;21(4):309-18.

[37] Chen W, Wang S, Li L, Zhang X, Wang Y. Test on mechanical characteristics of modified ginger nut. Rock and Soil Mechanics. 2018;39(5):1796-804.

[38] Moropoulou A, Bakolas A, Anagnostopoulou S. Composite materials in ancient structure. Cement & Concrete Composites. 2005;27(2):295-300.

[39] Li Z, Zhao L, Li L. Light weight concrete of Yangshao period of China: The earliest concrete in the world. Science China Technological Sciences. 2012;55:629-39.

[40] Kurdowski W. Cement and concrete chemistry. Beijing: China Architecture and Architecture Press; 1980. p. 369-532.

[41] Shao M, Li L, Chen W, Liu J. Investigation and modification of two kinds of Chinese traditional lime in cultural building relics. Journal of Cultural Heritage. 2019;36:118-27.

[42] Luo Y. Ancient cement. Science and Technology of Overseas Building Materials. 1997; 18(1):77.

[43] Li Z, Zhao L, Li L, Wang J. Research on the modification of two traditional building materials in ancient China. Heritage Science. 2013;1(1):27-37.

[44] Li L, Zhao Li, Li Z. Study on physical and mechanical properties of several kinds of lime materials in ancient Chinese architecture. Sciences of Conservation and Archaeology. 2014;26(3):74-84.

[45] Zhao L, Wang J, Li L. Study on physical and mechanical properties of sandstone grotto fissure grouting materials based on Yangshao cement. Sciences of Conservation and Archaeology. 2018;30(1):47-52.

[46] Zhang J, Wang N, Fan M. Experimental study on age performance of grouting material for firing ginger modified site soil crack. Chinese Journal of Rock Mechanics and Engineering. 2018;37(01):220-9.

[47] Wang N. Study on group anchorage effect of wood anchors in rammed soil sites. Lanzhou University. 2021.

[48] Wang X. New progress in research on key technologies for the protection of middle-soil sites in arid environments in China. Dunhuang Research. 2008;6:6-12.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

[49] Ren X, Zhang J, Wang N. The age performance of soil slurry in the site of burning ginger nut mixing site for anchoring of earthen sites. Journal of Materials Science and Engineering. 2017;35(01):62-6+86.

[50] Chen W, Zhang K, Zhang J. Laboratory experimental study on the mixing site soil slurry concretion body of burnt ginger nuts. Journal of Central South University. 2018;49(06):1519-25.

[51] Rassineux F, Petit J, Meunier A. Ancient analogues of modern cement: calcium hydrosilicates in mortars and concretes from Gallo-Roman thermal baths of western France. Journal of the American Ceramic Society. 1989;72(6):1026-32.

[52] Zhao L, Li L, Fan Z. Indoor research on the reinforcement materials of ancient tomb mural. Dunhuang Research. 2016;2:108-16.

[53] Li J, Zhang B. The research status and development trend of cementitious materials for cultural relics protection in China-Based on the quantitative analysis of journal papers in CNKI in the past 15 years. Sciences of Conservation and Archaeology. 2016;28(4):120-32.

[54] Zhao L, Wang X, Li L. Study on indoor screening of crack grouting materials for sandstone grottoes base-d on Yangshao cement. Sciences of Conservation and Archaeology. 2016;28(3):48-54.

[55] Ma Q, Chen G, Lu Y. Study on the reinforcement material of mural plaster in wet environment. Dunhuang Research. 2005;5:66-70.