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The research progress and Hotspot analysis of polymer cement mortar based on bibliometrics

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Ordinary cement mortar is commonly used in building engineering due to its high strength, affordability, and easy access to raw materials. However, it suffers from high shrinkage and poor impermeability, which result in reduced building service life and significant carbon dioxide emissions during production. Polymer additives have been found to enhance the mechanical properties of cement mortar, leading to increased interest in polymer cement mortar by researchers. This study collected and analyzed 420 papers published between 1995 and 2023 in the field of polymer cement mortar. The analysis included publication trends, author cooperation networks, national cooperation networks, published journals, co-citation of references, and keywords. The findings reveal a rapid publication growth from 2018 to 2023, with China making the most significant contribution in this field. Among the scholars, Ru Wang has published the highest number of articles in the field of polymer cement mortar, while Ohama's papers have been cited the most. The journal with the most articles is Construction and Building Materials. Research in polymer cement mortar focuses on mechanical properties, performance, hydration process, microstructure, and other related aspects. The reinforcement effect of polymer-modified cement mortar on reinforced concrete and applying superabsorbent polymer-modified cement mortar and polymer fiber in cement mortar have emerged as recent research frontiers. This study can help scholars quickly identify high-quality references and research frontiers in the field of polymer cement mortar while also providing research directions and ideas.

KEYWORDS

polymer cement mortar, bibliometric analysis, CiteSpace, VOSviewer, hotspot analysis

1 Introduction

The Cement mortar is widely used in civil engineering. It is composed of cement, sand, water, and other raw materials, offering high strength, cost-effectiveness, and easy availability of resources (Qin et al., 2018; Peng et al., 2020). Its construction performance is commendable, facilitating efficient production (Shi et al., 2011; Luigi et al., 2018). However, ordinary cement mortar does have certain drawbacks. It exhibits significant shrinkage, making it susceptible to cracking and deformation, which can adversely affect the lifespan and appearance of buildings (Li et al., 2020). Additionally, ordinary cement mortar has poor impermeability and durability and is easily eroded by moisture, which leads to mortar falling off and damage (Liu et al., 2021; Qu et al., 2023). Moreover, cement production has a significant impact on the natural environment. The global output of cement has risen from

TABLE 1 The main pollutants emitted by ordinary cement mortar and the corresponding hazards.

Pollutant	Hazard
CO ₂	Carbon dioxide leads to global warming, affects biodiversity and human health. Carbonization will affect the mechanical properties and service life of buildings
SO ₂	Sulfur dioxide pollutes the atmosphere, causes acid rain, corrodes the surface of buildings, resulting in a decrease in the strength and durability reduction of building structures
NO,NO ₂	Nitrogen oxides can lead to air pollution, forest destruction, red tide phenomena and the deterioration of reinforced concrete structures
Dust	Dust not only causes pollution to the environment, but also seriously affects the respiratory health and overall physical health of workers

1.39 billion tons in 1995 to 4.4 billion tons in 2021. This increase in production has resulted in substantial carbon dioxide emissions, with approximately 0.86 tons of carbon dioxide released per ton of cement produced. These carbon emissions contribute to around 5% of global carbon emissions yearly, significantly impacting climate change and environmental pollution (Monteiro et al., 2017; Belaïd, 2022; Singh et al., 2022; Hanifa et al., 2023). Table 1 shows the main pollutants emitted by ordinary cement mortar and their harms.

To mitigate carbon emissions from cement production and enhance the longevity of structures, it is imperative to enhance the fracture resistance and durability of cement mortar. With the development of chemical technology, people realize that the relaxation motion of macromolecular chain segments in polymers makes them show unique toughness, elasticity, and viscosity. Therefore, applying organic polymers with good flexibility, cohesiveness, tensile strength, impact resistance, and deformation properties to cement-based materials produces an interdisciplinary subject between polymer science and inorganic cementitious material chemistry. Mortar made of cement, fine aggregate, polymer, and the appropriate amount of water in a specific ratio is called polymer cement mortar, which can also be called polymer-modified cement mortar (Aggarwal et al., 2007; Kucharczyková et al., 2019). The production process of polymer cement mortar is similar to that of traditional cement mortar, involving four main steps: raw material selection, mix ratio determination, mixing, and curing. However, polymers may require pretreatment, leading to a more complex mixing process. The addition time and proportion of polymers must be carefully controlled. Specific curing and solidifying conditions may be necessary for certain polymer cement mortars. Table 2 presents the impact of various polymer cement mortars on reducing carbon emissions, categorized accordingly. The reduction in carbon emissions from different polymer cement mortars primarily arises from their capacity to enhance building material performance, thereby prolonging service life, lowering maintenance needs, and potentially decreasing energy consumption and emissions through alterations in the production process.

Polymer additives are commonly categorized into four groups: redispersible rubber powder, water-soluble polymer, polymer

TABLE 2 The carbon pollution reduction effects of different types of polymer cement mortar.

Polymer cement mortar types	Primary effect
Polymer waterproof mortar	It can reduce the energy loss and structural damage caused by leakage and prolong the building maintenance cycle
Insulation polymer-modified mortar	It enhances the thermal insulation performance of the building, effectively reduces the energy consumption of heating and cooling, thereby directly reducing carbon emissions
Reinforced polymer-modified mortar	It can enhance the stability of the structure, making the building more durable and reducing the reconstruction due to structural damage, which is indirectly beneficial to carbon emission reduction
Polymer patching mortar	Efficient base repair reduces the use of new materials and helps to reduce the carbon emissions in the production and processing process of the overall building materials
Other auxiliary polymer mortar materials (such as tile adhesives and interface agents)	It can improve the construction efficiency, increase the adhesive force between materials, and reduce the chance of shedding and redoing, indirectly reducing carbon emissions

emulsions, and liquid polymer. However, liquid polymer is not widely utilized (Ohama, 1998). Examples of redispersible rubber powders include ethylene-vinyl acetate copolymer and vinyl acetate-ethylene-methyl methacrylate copolymer (Tarannum et al., 2020; Tarannum and Pooja, 2022; Balagopal et al., 2023). Water-soluble polymers, such as polyacrylic acid and polyacrylamide, are known for their water retention, thickening, retarding, drag reduction, and dispersion properties (Rai and Singh, 2005; Li et al., 2020). Polymer emulsions, like styrene-acrylate copolymer emulsion, can enhance the impermeability and durability of cement mortar (Yang et al., 2023).

As an organic and inorganic composite material, polymer cement mortar exhibits favorable properties. Adding polymer particles to cement mortar fills the holes, and the polymer film effectively seals them, enhancing the impermeability of the cement mortar. Furthermore, the polymer significantly enhances various characteristics of cement-based materials, including fluidity, water retention, durability, chemical corrosion resistance, freeze-thaw resistance, mechanical strength, and elongation (Chung, 2004; Eren et al., 2017; Kujawa et al., 2021; Zhang et al., 2021). The addition of super absorbent polymers to cement mortar in practical engineering applications can effectively repair cracks and enhance sulfate resistance (Afzal et al., 2016). Furthermore, polymer cement mortar has been successfully utilized in projects aimed at repairing historical masonry and enhancing resistance to salt erosion (Tc, 2012). After incorporating polymer materials into traditional

cement mortar, initial construction costs may be higher. However, polymer cement mortar offers improved construction performance, durability, and mechanical properties. This can lead to a decrease in rework rates and maintenance costs during construction, as well as a reduction in long-term maintenance and repair expenses (Bozkurt and İslamoğlu, 2013). Consequently, engineering practitioners and researchers have increasingly focused on the potential of polymer cement mortar.

Scholars have extensively studied the research status of polymer cement mortar. Zhang et al. (2021) comprehensively analyzed the mechanical properties, microstructure, and polymer reinforcement mechanism of polymer cement mortar. Bahraq et al. (2022) utilized molecular simulation technology to investigate the interaction between polymers and cement. However, most documents focus on qualitative analyses of polymer cement mortar, which often involve subjective explanations. This approach can sometimes result in an overestimation or underestimation of the contribution of specific authors, either intentionally or unintentionally. To address this issue, conducting a quantitative study of a specific field using bibliometrics can objectively assess the field's current state, research areas of interest, and development trends.

This study employed the bibliometrics method to quantitatively visualize the related literature of polymer cement mortar from 1995 to 2023. The research status, hotspots, and evolution trends in the field of polymer cement mortar were analyzed by constructing a knowledge map using visualization software. The paper is organized as follows: The second part summarizes the leading analysis methods, analysis tools, and data acquisition methods. The third part focuses on the output distribution and cooperation network, knowledge base, research topics, and frontier analysis of polymer cement mortar. Finally, the paper concludes with a discussion on the prospects of polymer cement mortar.

2 Data source and method

2.1 Method

Bibliometrics is an interdisciplinary science that uses mathematical and statistical methods to analyze various forms of knowledge quantitatively (Diem and Wolter, 2013). The concept of bibliometrics was formally introduced by Pritchard in 1969 and has since gained wide recognition in academic circles (Pritchard, 1969). During the analysis process, scholars can obtain detailed data on authors, keywords, periodical publications, countries, research institutions, and cited documents (Abramo et al., 2011). When selecting bibliometric analysis software, three core criteria should be considered: Firstly, the software should be able to extract critical information from the literature automatically. Secondly, it should be capable of conducting comprehensive and multi-dimensional analysis of the collected literature. Lastly, the software should have efficient data visualization functions to ensure a clear and intuitive presentation of the analysis results (Zhu et al., 2023).

Citespace and VOSviewer are widely used literature information visualization software (Pan et al., 2018). Citespace software is used to analyze research trends in a specific field and present them visually, allowing users to predict the field's turning point and

TABLE 3 Data sample source.

Category	Specific retrieval method
Database selected	Web of Science core collection
Citation indexes	SCIE
Time range	January 1995 to December 2023
Language	English
Search terms	TS = [(Polymer) AND ("cement mortar" OR "cement mortars" OR "cement and sand mortar")]
Document category	Article and review
Data extraction	Export with full records and cited references in plain text format
Quantity initially retrieved	558

future development (Chen, 2006). VOSviewer software provides various visual views on authors, journals, countries, etc (van Eck and Waltman, 2010). Both software complement each other, resulting in more prosperous and comprehensive analysis results (Haghani, 2023). This study used VOSviewer and CiteSpace (version 6.2. R6) software to analyze data collected from the literature. The analysis includes authors, national cooperation relations, periodicals, research hotspots, and CiteSpace software, specifically used to study polymer cement mortar's evolution path and research frontier.

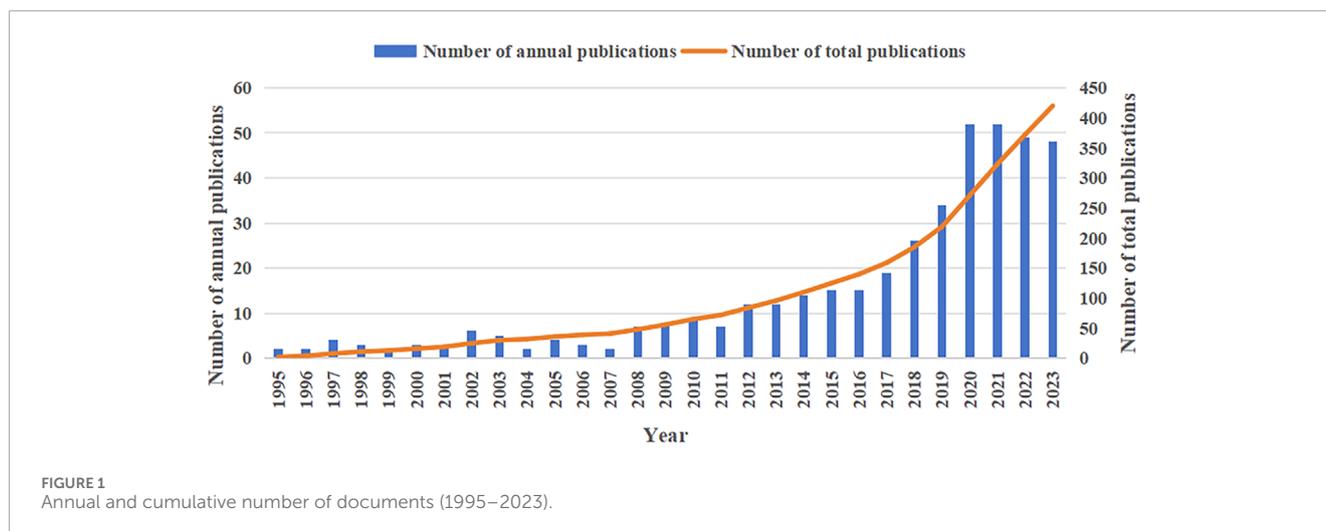
2.2 Data source

To ensure the comprehensiveness and authority of the analyzed data, the Web of Science was employed as the primary source for this study (Thelwall, 2008). The data sources and retrieval methods are presented in Table 3. A total of 558 documents were retrieved using the methods described in the table. However, since the retrieved literature may not directly relate to the research theme, each was carefully screened before analysis. As a result, 420 valid documents were obtained, consisting of 408 research papers and 12 reviews.

3 Results and discussion

3.1 Yearly distribution and growth trends

The annual number of papers published in a particular discipline reflects the level of scientific research and the speed of development in this field to a certain extent. From 1995 to 2023, the published volume of polymer cement mortar is shown in Figure 1. The number of papers published in this field shows an overall growth trend. Based on the yearly increase in publications, the trend can be categorized into two distinct phases. The initial phase, spanning from 1995 to 2017, exhibits a sluggish growth pattern with an annual publication count remaining below 20. Remarkably, the peak of publications was observed in 2020 and 2021, with 52 articles. Subsequently,



between 2018 and 2023, a rapid surge in published articles occurred, indicative of considerable academic interest and a subsequent phase of swift advancement in this research domain.

3.2 Document output distribution and cooperation network

3.2.1 Bibliometric analysis of the author

The author's co-occurrence analysis aims to discuss the research and cooperation of polymer cement mortar, identify the key authors in this field and their collaboration relationships. Using VOSviewer software, authors who have published at least four articles were counted, and the results are presented in Table 4. From 1995 to 2023, a total of 1,475 authors were identified. Among them, the top four authors who published the most articles were Ru Wang, Tamon Ueda, Bo Wang, and Dawei Zhang, with 10, 9, 7, and 7 articles respectively. The most frequently cited authors were Ru Wang (343 citations), Tamon Ueda (207 citations), and Manicka Dhanasekar (193 citations). The authors with the highest average number of citations per article were Manicka Dhanasekar (48.25), Ru Wang (34.3), and J. M. Fernandez (28). Ru Wang excelled in the number of published papers, total citations, and average citations, making significant contributions to the research field of polymer cement mortar. Wang's research primarily focuses on investigating the impact of various polymers on the properties of calcium sulfoaluminate cement (Li et al., 2018; Wang et al., 2021).

For the authors who have published at least three articles, the author's cooperation network diagram is drawn by VOSviewer software, as shown in Figure 2. The three most apparent clusters in the figure represent the most critical cooperative research teams in polymer cement mortar. The first significant cluster is centered around Biqin Dong and consists of Xiangming Kong, Lin Li, Peiming Wang, Feng Xing, and Ru Wang. This cluster primarily focuses on studying the impact of different types of polymers on the properties of cement mortar (Li et al., 2020; Li et al., 2021). The second central cluster revolves around Bo Wang and includes Shinichi Hino, Lianheng Cai, Rui Guo, and Kimataka Uji. Their research primarily investigates the reinforcement effect of fiber-reinforced

polymer grids and polymer cement mortar on reinforced concrete beams (Guo et al., 2019; Wang et al., 2020). The third significant cluster centers around Tamon Ueda and comprises Mahmudul Hasan Mizan, Koji Matsumoto, Khuram Rashid, and Dawei Zhang. This cluster has the highest number of collaborations and mainly explores the bonding properties of polymer cement-based materials (Qian et al., 2016; Mizan et al., 2020).

In the cooperative network, the two authors with the most significant number of cooperators are Bo Wang and Tamon Ueda, with 7 and 5 cooperators, respectively. These authors actively collaborate with other scholars, which promotes the output of their papers and enhances the overall influence of their work. Based on the number of cooperative papers among authors, three significant cooperative relationships have been identified: Tamon Ueda-Dawei Zhang, Tamon Ueda-Khuram Rashid, and Koji Matsumoto-Mahmudul Hasan Mizan. The collaboration among these authors has formed meaningful cooperative relationships in the research of polymer cement mortar. The latest research on author cooperation has included a study by Tamon Ueda, Rashid, Khuram, and Dawei Zhang on the flexural bearing capacity of reinforced concrete beams with PCM cover layers in high-temperature environments. They introduced an average crack spacing method that takes into account crack spacing (Rashid et al., 2023). Additionally, recent research by (Hasan Mizan and Matsumoto, 2023) demonstrated that adding silica fume can enhance the bond strength between PCM and concrete, prolong the occurrence of debonding failure, and improve ductility.

3.2.2 Bibliometric analysis of the country

From 1995 to 2023, 52 countries conducted research in the field of polymer cement mortar. Table 5 presents the top 10 countries with the highest number of papers. Based on the paper output, China, Japan, and South Korea emerged as the leading countries, with 179, 43, and 41 papers, respectively. Notably, China's publications account for 42.62% of the total, significantly surpassing other countries and establishing itself as the primary contributor in the field of polymer cement mortar. Additionally, Table 5 reveals a significant disparity in the distribution of countries, with a few nations dominating the research output. A regional analysis indicates that China, Japan,

TABLE 4 Authors with a minimum of 4 publications.

Rank	Author	Publication	Citations	Average citations	Total link strength
1	Wang, Ru	10	343	34.30	4
2	Ueda, Tamon	9	207	23.00	15
3	Wang, Bo	7	90	12.86	12
4	Zhang, Dawei	7	162	23.14	12
5	Guo, Rui	6	102	17.00	12
6	Rashid, Khuram	6	132	22.00	10
7	Chen, Huaxin	5	65	13.00	1
8	Dong, Biqin	5	73	14.60	4
9	Ran, Qianping	5	54	10.80	3
10	Dhanasekar, Manicka	4	193	48.25	2
11	Fernandez, J. M	4	112	28.00	9
12	Jiang, Yujing	4	44	11.00	0
13	Li, Gengying	4	49	12.25	0
14	Matsumoto, Koji	4	21	5.25	5
15	Mizan, Mahmudul Hasan	4	21	5.25	5

South Korea, and India published 293 articles, representing 68.1% of the total. This highlights the substantial contributions made by Asia to the study of polymer cement mortar. Moreover, the United States exhibits a remarkable citation count of 36.6, indicating a high academic standard in this field.

Using VOSviewer and Scimago Graphica software, the countries with more than three articles are visually analyzed, and the co-occurrence map of national cooperation is drawn as shown in Figure 3. Figure 3 displays the relationship between the number of published documents and the size of the round node. A larger round node indicates a higher number of published documents. Additionally, the strength of cooperation is represented by the connection line of the node. The thickness of the connection line indicates the frequency of cooperation between two countries. From the perspective of the number of cooperative relations, it is found that China has cooperative relations with 15 countries in the cooperative network, and its cooperation with other countries ranks first, indicating that China is the research center of polymer cement mortar at present, followed by the United States (11) and Australia (9).

From the analysis of the cooperation strength of countries, the top five cooperation relationships are China-Japan, China-United States, China-Australia, Japan-South Korea, and China-Pakistan. China has always been in a leading position in this field of cooperation. Its partners are mainly in Asia, North America, and Oceania, with relatively few cooperations with Europe. The countries with the highest cooperation relationships form

the core bilateral relationships in international polymer cement mortar research.

3.2.3 Bibliometric analysis of the journal

Journals play a crucial role in disseminating research findings in polymer cement mortar. A comprehensive analysis of 420 papers using VOSviewer revealed that these papers were published across 131 journals. Table 6 presents the top ten journals in this research area. Construction and Building Materials, Materials, and Cement and Concrete Research emerged as the three leading journals, with 94, 22, and 17 articles, respectively. These journals also garnered significant citation numbers, with Construction and Building Materials receiving 2,518 citations, Materials receiving 196 citations, and Cement and Concrete Research receiving 1,316 citations. Construction and Building Materials stands out by publishing a considerably higher number of articles than other journals, indicating its popularity among experts in the field. This journal focuses on the study of building materials and their application technologies, covering topics such as cement, concrete reinforcement, bricks and mortar, additives, steel, polymers, and recycled materials. Research on polymer cement mortar is closely linked to these areas of study. As an open-access journal, Materials has substantially contributed to advancing this research area. Cement and Concrete Research and Cement & Concrete Composites boast the highest average citation numbers, exceeding 70. This suggests that articles published in these two journals are of exceptional quality, making them the top-tier journals

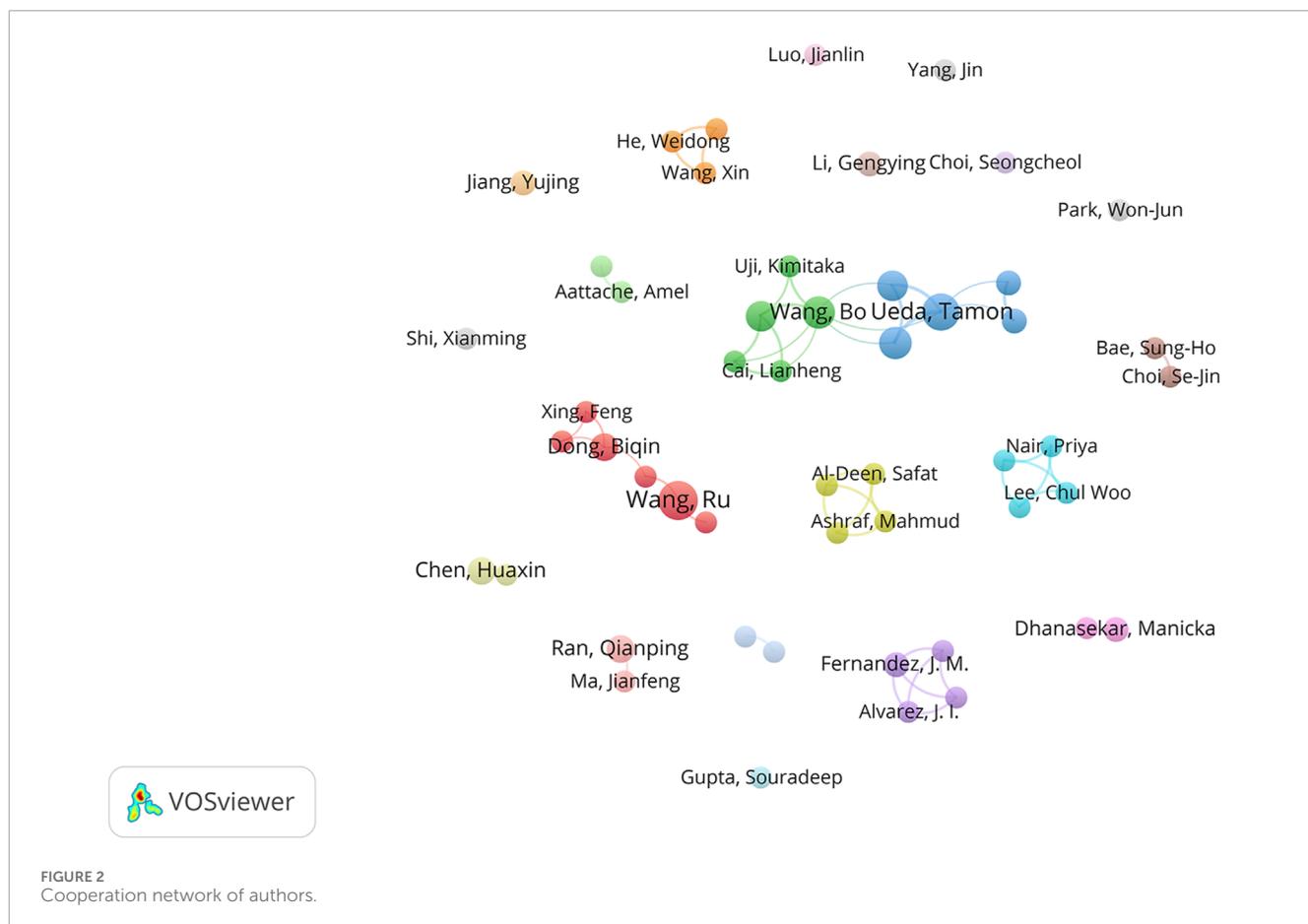


TABLE 5 Top10 countries in the field of polymer cement mortar.

Rank	Country	Publications	Citations	Average citation per publication	Percentage (%)
1	China	179	3,045	17.01	42.62
2	Japan	43	1,014	23.58	10.24
3	South Korea	41	379	9.24	9.76
4	USA	25	915	36.60	5.95
5	India	23	583	25.35	5.48
6	Australia	20	511	25.55	4.76
7	Poland	16	192	12.00	3.81
8	Brazil	12	193	16.08	2.86
9	Turkey	12	260	21.67	2.86
10	Spain	11	318	28.91	2.62

in this domain. They primarily focus on research related to cement-based materials, energy-saving building materials, and various composite materials. Furthermore, these journals feature research outcomes concerning polymer cement-based materials as one of their critical focal points.

3.3 Co-citation analysis

By analyzing the co-cited literature in the field of polymer cement mortar, we can get a knowledge base in this field. The frequently cited documents are classic works or significant

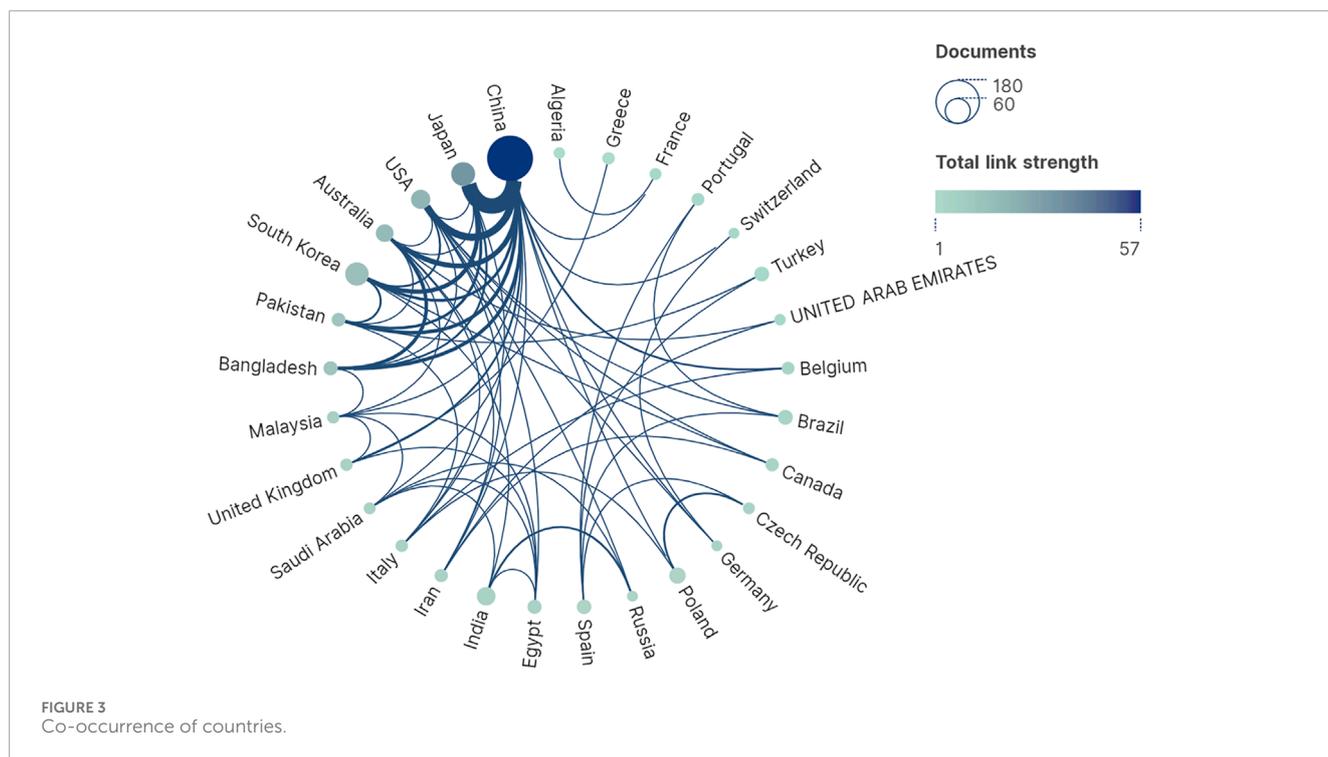


TABLE 6 Top10 journals in the field of polymer cement mortar.

Rank	Source	Publications	Citations	Average citation
1	Construction and Building Materials	94	2,518	26.79
2	Materials	22	196	8.91
3	Cement and Concrete Research	17	1,316	77.41
4	Cement & Concrete Composites	16	1,174	73.38
5	Journal of Materials in Civil Engineering	15	242	16.13
6	Journal of Building Engineering	14	132	9.43
7	Polymers	12	66	5.50
8	Journal of Applied Polymer Science	9	90	10.00
9	Case Studies in Construction Materials	8	36	4.50
10	Materials and Structures	8	117	14.63

theoretical achievements in a particular field. Table 7 shows the five most cited documents.

Ohama has made significant contributions to the field of polymer cement mortar, and his research results are highly cited. His documents, namely, “Polymer-based Acknowledgements” and “Handbook of Polymer-Modified Concrete and Mortars: Properties and Process Technology,” have received 45 and 40 citations, respectively. In these two documents, he extensively studied the classification of polymers, the modification mechanism, simplified polymer models, and the properties of polymer cement

mortar (Ohama, 1995; Ohama, 1998). These studies laid a strong foundation for subsequent research in this area. Many scholars refer to these two documents in their introductions. Aggarwal et al. (2007) researched the modification of cement mortar using epoxy and acrylic emulsions. They discovered the modified cement mortar exhibited high strength and excellent resistance to chloride ion and carbon dioxide penetration. Sakai and Sugita (1995) investigated the microstructure and compounding mechanism of polymer-modified cement mortar. Through cryo-SEM observations, they identified dispersed polymer particles and

TABLE 7 Top 5 highly cited references.

Rank	Title	Citations	Year
1	Polymer-Based Admixtures (Ohama, 1998)	45	1998
2	Handbook of Polymer-Modified Concrete and Mortars: Properties and Process Technology (Ohama, 1995)	40	1995
3	Properties of Polymer-modified Mortars Using Epoxy and Acrylic Emulsions (Aggarwal et al., 2007)	32	2007
4	Composite Mechanism of Polymer Modified Cement (Sakai and Sugita, 1995)	28	1995
5	Physical and Mechanical Properties of Styrene-butadiene Rubber Emulsion Modified Cement Mortars (Wang et al., 2005)	26	2005

polymer films on the surface of PMC samples, thereby revealing the compounding mechanism of polymer-modified cement. This study provided a theoretical and experimental basis for applying polymer-modified cement. Wang et al. (2005) explored the modification of cement mortar using styrene-butadiene rubber emulsion. The study found that the apparent bulk density, compressive strength, and bending strength of polymer-modified mortar were influenced by the ratio of polymer to cement. Additionally, the study revealed the modification mechanism of polymer to cement mortar from a microstructural perspective. Overall, these five references primarily focus on polymer cement mortar's performance, reaction mechanism, and microstructure.

Using VOSviewer software, a co-citation map of references was created with a threshold of 9. A total of 65 references with the highest co-citation times were selected to draw the map, as shown in Figure 4. The graph is divided into four clusters, represented by different colors. The red cluster primarily investigates the microstructure and reaction mechanism of polymer-modified cement mortar, examining the impact of various polymers on cement mortar properties (Barluenga and Hernández-Olivares, 2004; Wang et al., 2005; Aggarwal et al., 2007). The blue cluster focuses on the influence of superabsorbent polymers (SAP) on the shrinkage and strength of cement-based materials (Jensen and Hansen, 2001; 2002; Justs et al., 2015). The yellow cluster concentrates on applying waste plastics in cement mortar and concrete (Hannawi et al., 2010; Saikia and de Brito, 2012). Lastly, the green cluster centers on the research of polymer cement mortar for beam reinforcement (Zhang et al., 2011; Zheng et al., 2016; Guo et al., 2018).

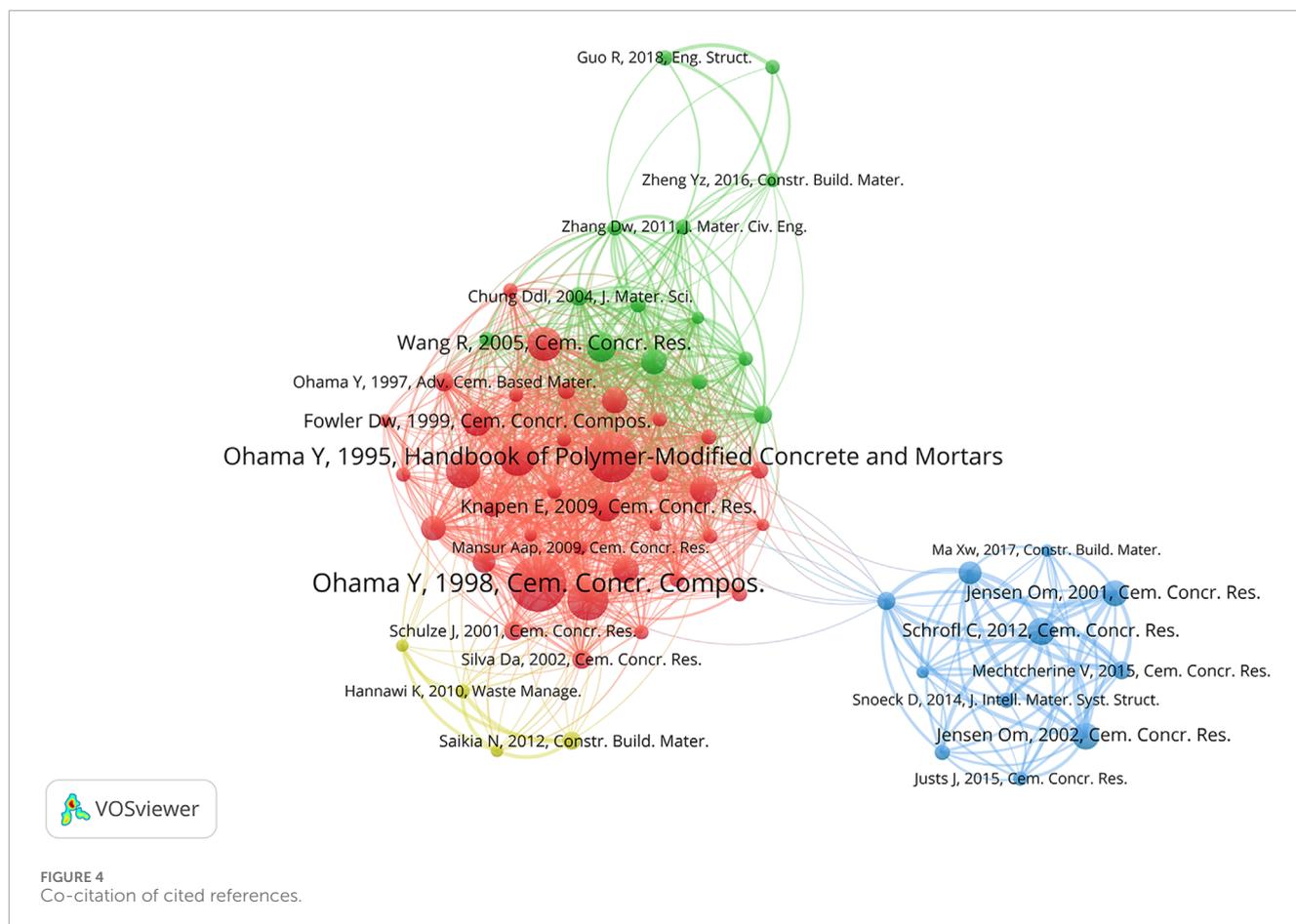
3.4 Bibliometric analysis of keywords

Keywords play a crucial role in bibliometric analysis, as they provide insights into the research focus in the field of polymer cement mortar. A keyword density map was generated using VOSviewer software to identify the research hotspots in this field. Synonyms were merged, and only keywords with a co-occurrence frequency of 8 or more were considered. The keyword density view, depicted in Figure 5, illustrates the frequency of co-occurrence for each keyword. The brightness of the figure indicates a higher frequency of co-occurrence. The analysis reveals that keywords such as concrete, strength, mechanical property, performance, microstructure, cement mortar, behavior, polymer,

durability, and hydration are representative terms in the polymer cement mortar field. Notably, the co-occurrence frequency of concrete is significantly higher (142 times) than other keywords. This can be attributed to the close relationship between concrete and mortar, as scholars focus on concrete's strength, durability, and workability, which are closely tied to the study of cement mortar. Based on these high-frequency keywords, the research on polymer cement mortar can be categorized into two main areas: the investigation of mechanical properties in polymer-modified cement-based materials and the exploration of microstructure and hydration reactions in polymer cement mortar.

The mechanical properties of polymer-modified cement-based materials are the most concerning content of scholars, and the related research results are the most. High-frequency keywords such as concrete, strength, mechanical property, performance, and behavior show the critical contents of the study. When polymer is added to cement mortar, it often reduces compressive strength and improves the toughness. Adding ethyl acetate copolymer or styrene-butadiene rubber into cement mortar will increase porosity, hinder cement hydration, and lower compressive strength (Peng et al., 2020). Latex styrene-butadiene is added to cement mortar, the compressive strength of cement mortar decreases with the increase of the ratio of polymer to cement, and the bending strength of cement mortar increases when the ratio of polymer to cement is greater than or equal to 10% (Pascal et al., 2004). The toughness of epoxy resin emulsion-modified mortar is related to environmental temperature. The polymer mortar's fracture energy and toughness increase with the decrease in test temperature (Reis et al., 2014). Polyvinyl alcohol fiber can reduce the shrinkage strain of cement mortar and the damage caused by it. It has remarkable ductility and energy absorption capacity and can enhance the toughness of cement mortar (Zanotti et al., 2014).

Alongside compressive strength, the bond strength of polymer cement mortar is also a crucial area of research. Currently, there is a greater focus in academic research on the bonding interaction between polymer cement mortar and concrete and bricks, with fewer studies addressing the interaction with steel, wood, and glass. The bonding effectiveness between polymer cement mortar and concrete is influenced by various factors such as temperature, humidity, and drying shrinkage. In environments with high temperature and humidity, the disparity in volume change between the materials can create tensile stress, leading to crack formation (Rashid et al., 2015). On the other hand, the bonding strength between polymer cement mortar and bricks is dependent on polymer content, water-binder



ratio of the cement mortar, and aggregate content. Lower polymer content affects bonding strength based on water and aggregate amounts, while higher polymer content enhances bonding strength independently of aggregate quantity (Papaioannou et al., 2019).

High-frequency keywords such as microstructure, hydration, durability, pore structure, and permeability indicate that scholars pay great attention to the microstructure of polymer cement mortar and the hydration process of cement. Scholars study the interaction mechanism between polymer and cement mortar from the microscopic point of view and explore the reasons for enhancing the working performance and mechanical properties of polymer cement mortar. From a physical perspective, polymer particles can fill the pores after the polymer is added to cement mortar, and polymer particles will also form polymer films. The polymer films wrap cement paste and hydration products, which can improve the pore structure of composite mortar and show good impermeability in macro (Barluenga and Hernández-Olivares, 2004; Ramli and Akhavan Tabassi, 2012). The theoretical model of polymer film formation in cement mortar, the formation time of polymer film, and the lowest formation temperature of polymer film will all affect the film formation effect (Wang et al., 2016). From a chemical standpoint, functional groups in polymers such as hydroxyl, carboxyl, and ester groups will react chemically in cement paste, thus delaying the process of cement hydration. In the alkali-rich environment, the ester group of acrylate is hydrolyzed to form a

carboxyl group, and the carboxyl group reacts with $\text{Ca}(\text{OH})_2$ to form a new product $\text{Ca}(\text{HCOO})_2$ (Wang et al., 2015). The ester functional groups of polymers can also absorb free and adsorbed calcium ions to form metal complexes (Ilango et al., 2021).

Durability is a critical performance factor of polymer cement mortar, encompassing erosion resistance, freeze-thaw resistance, and adaptability to high temperature and high humidity environments. Numerous studies have been conducted by scholars focusing on the durability of polymer cement mortar. (Bhattacharya et al., 1983). investigated the durability of polymer cement mortars in sulfuric acid and hydrochloric acid solutions, highlighting the significant impact of the interaction between cement and polymer on material durability. (Schulze and Killermann, 2001). examined the long-term performance of polymer modified mortar in both outdoor and indoor settings, noting that the polymer modified cement mortar maintained stable adhesion, flexural, and compressive strength over a 10-year period. The frost resistance of polymer cement mortar is influenced by the type of polymer used. Among the three polymers studied (styrene butadiene rubber (SBR), styrene acrylic ester (SAE), and polyacrylic ester (PAE)), only SBR has been shown to enhance the frost resistance and freeze-thaw cycle performance of sulphoaluminate cement mortar (Li et al., 2018). Research by (Knapen and Gemert, 2009) revealed that in high humidity conditions, water-soluble polymer films dissolve in water, leading to a significant decrease in the flexural strength of polymer

TABLE 8 Top 11 keywords with the strongest citation bursts.

Keywords	Year	Strength	Begin	End
Polymer	1995	2.66	1995	2014
Silica fume	2000	2.61	2000	2002
Polymer-modified mortar	2002	4.66	2002	2012
Cement mortar	2003	2.76	2010	2012
Hydration	1995	2.7	2010	2013
Capacity	2017	2.06	2017	2020
Water	2014	2.97	2018	2021
Frp	2009	2.12	2018	2021
Steel	2020	3.34	2020	2021
Flexural behavior	2020	2.5	2020	2021
Bond property	2013	2.08	2021	2023

a recent focus on the influence of polymers on the flexural capacity and bond performance of reinforced concrete beams. Research has demonstrated that the use of carbon fiber reinforced polymer (CFRP) grids and sprayed polymer-cement-mortar (PCM) can enhance shear resistance, flexural stiffness, and ductility of reinforced concrete (RC) beams (Wang et al., 2020). Furthermore, reinforcing hollow slab beams with prestressed steel strands and polyurethane cement composite materials has been found to greatly improve flexural bearing capacity, crack resistance, and stiffness in experimental tests (Li et al., 2023).

To better understand the evolution of research on polymer cement mortar and identify emerging research hotspots, this study utilized the timezone view function in CiteSpace software to represent keyword trends visually. Only keywords with a frequency of at least five times were included to ensure clarity. Figure 6 displays the keyword timezone view, where the position of each node indicates the year of the keyword's first appearance, and the node's size represents the keyword's cumulative frequency.

Based on the comprehensive analysis of Table 8 and Figure 6, the research content of polymer cement mortar from 1995 to 2023 can be categorized into four distinct phases. The first period is from 1995 to 2000, and the research of polymer cement mortar is in the initial exploration period, with the burst term polymer and the high-frequency keywords concrete, portland cement and hydration. During this period, although research on polymer cement mortar has been carried out, the focus of academic research is still on polymer and concrete. The second period is from 2001 to 2007, during which the mechanical properties of polymer cement mortar are mainly studied. Polymer-modified mortar, the burst term with the highest strength, appeared in 2002, showing that academic circles' research focus has shifted to polymer cement mortar. Many high-frequency keywords related to mechanical properties have appeared, such as mechanical property, bond strength, compressive strength, and strength, indicating that the

research on mechanical properties of polymer cement mortar has increased rapidly and continues. The third period is 2008-2017. At this stage, polymer cement mortar's microstructure and pore characteristics are mainly studied. High-frequency keywords related to microstructure and pore, such as microstructure, pore structure, durability, autogenous shrinkage, and shrinkage, appear one after another. Scholars focus on polymer cement mortar's durability, impermeability, and shrinkage. The fourth period is from 2018 to the present; research on polymer cement mortar has entered a stage of diversified development. During this period, key terms such as water, frp, steel, flexible behavior, and bond property have emerged. "water" is associated with superabsorbent polymer, while frp is linked to polymer fiber. Steel, flexible behavior, and bond properties are also relevant to reinforced concrete beams. In recent years, there has been a growing interest in the reinforcement effect of polymer-modified cement mortar on reinforced concrete, as well as the application of SAP-modified cement mortar and polymer fiber in cement mortar. Researchers have been exploring these areas as emerging research frontiers.

4 Prospect

In addition to polymer cement mortar, there are also ecological mortar and self-healing cement mortar, among other advanced materials used in buildings. Ecological mortar utilizes waste materials such as tailings, waste residues, and garbage in its production process to protect the environment. However, there are technical challenges in production, including unstable chemical composition and significant variability (Srivastava and Singh, 2020). Self-healing cement mortar offers self-repairing and regenerative properties, enhancing the durability and long-term stability of structures, although its technical maturity remains relatively low (Wu et al., 2012). In comparison, polymer cement mortar has been extensively researched, boasting mature theory, non-toxic and environmentally friendly products, and stable, high-performance characteristics, positioning it with more advantages for future development.

- (1) Develop energy-saving and environment-friendly polymer cement mortar. The increasing global attention towards environmental protection and renewable resource utilization has made green polymer cement mortar a prominent area of research. Recycling waste rubber powder and plastic particles, decomposing and purifying them, and transforming them into pure recycled polymer can effectively promote material recycling and resource conservation (Feng et al., 2022).
- (2) Determine the appropriate polymer as an admixture. Various polymers, such as solid particles, latex, anionic, cationic, and nonionic forms, can be used as additives. Price, toxicity, and ecological impact should be considered when selecting polymers, as they are crucial in limiting the widespread adoption of polymer bentonite-modified mortar. Therefore, future research should focus on selecting polymers based on engineering requirements.
- (3) Developing compound polymer cement mortar is a promising avenue of research. Since each polymer has unique properties, combining multiple polymers can enhance their

its service life. The recycling and utilization of materials play a crucial role in environmental impact and should be considered a significant research focus for the future. There is currently a lack of research on the complete life cycle of polymer cement mortar within the academic community. Conducting such research could significantly enhance the economic and social advantages of construction projects, ultimately leading to sustainable development.

5 Conclusion

This study employed bibliometric analysis to examine 420 articles published between 1995 and 2023 in the field of polymer cement mortar. The analysis utilized VOSviewer and CiteSpace software to identify the changing trend of publications, author distribution, national cooperation networks, and periodicals. Additionally, classical references in this field were identified through co-cited reference analysis. Finally, a keyword co-occurrence analysis was conducted to identify research hotspots and development trends in recent years systematically. The following conclusions were drawn:

- (1) The research on polymer cement mortar has seen a steady increase, with a slow growth stage observed from 1995 to 2017, followed by a rapid growth stage from 2018 to 2023. Among the countries involved in this field, China has published the highest number of papers, accounting for 42.62% of the total publications, surpassing other countries by a significant margin. Ru Wang emerges as the most prolific scholar in terms of article publications, while Tamon Ueda stands out for his collaborations with other researchers. Construction and Building Materials is the leading journal regarding the number of articles published in this field. A co-cited reference analysis reveals that Ohama authored the two most influential documents. In these papers, Ohama extensively studied the classification of polymers, the modification mechanism and simplified model of polymers, as well as the properties of polymer cement mortar. These foundational studies have contributed significantly to subsequent research in the field.
- (2) The research focus of polymer cement mortar is primarily on mechanical properties, performance, hydration process, and microstructure. Based on the frequency of keywords and relevant burst terms, the study on polymer cement mortar from 1995 to 2023 can be categorized into four distinct phases. The initial exploration period spans from 1995 to 2000. From 2001 to 2007, extensive investigations were conducted on the mechanical properties of polymer cement mortar. Between 2008 and 2017, the years witnessed a significant emphasis on studying the microstructure and pore characteristics of polymer cement mortar. Since 2018, research on polymer cement mortar has entered a stage characterized by diversified development. Notably, recent frontiers include exploring the strengthening effect of polymer-modified cement mortar on reinforced concrete and investigating SAP-modified cement mortar and the applications of polymer fiber in cement mortars.

While this study has made specific contributions, it is essential to acknowledge its limitations. Firstly, the study solely relies on the Web of Science core collection database and focuses only on English literature, which may not provide a comprehensive overview. In future research, including multiple databases to ensure a more comprehensive dataset would be beneficial. Additionally, engaging in active communication with scholars in this field can help gain a more objective understanding of the research content and enhance the overall quality and level of research.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#), further inquiries can be directed to the corresponding author.

Author contributions

PW: Writing—original draft. FW: Writing—review and editing. MM: Writing—review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmats.2024.1401816/full#supplementary-material>

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