Hydration Retardation in Cement-Based Materials: Chemical Admixtures, Natural Retarders, and Emerging Alternatives – A Review

Ahmed Hafedh Mohammed[1], Lubna S. Kamil[2], Ibrahim Abdulwahhab Atiyah[1], Rasha A. Alsamurie[3]
[1]Department of Materials Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
[2]Project and Construction Division, Mustansiriyah University, Baghdad, Iraq.
[3]Department of Civil Engineering, College of Engineering, Baghdad University, Baghdad, Iraq.

Abstract
Hydration Retardation: A Review of Literature relating to Cement-based Materials. Actually, hydration retardation is one of the major methods used to handle fresh as well as hardened properties of cement-based materials. This review would provide a systematic update of literature available regarding methods for hydration retardation with special focus being given to the main types of methods for hydration retardation. This would also include conventional methods of using chemicals such as lignosulfonate compounds, sugar derivatives, as well as organic acids. There is a growing interest in natural and bio-based retarders based on agricultural by-products and plant extracts, which may have lower environmental impact but do not sacrifice a performance that is satisfactory. Moreover, the new alternatives such as bio-based polymers, nanomaterials, and high-level synthetic compounds are also discussed in terms of their effects on the kinetics of hydration, microstructural formation, and long-term stability. The review is also conducted on experimental and analytical methods to assess hydration retardation like calorimetry, spectroscopic methods, and microstructural analysis. The gaps in the existing knowledge are found especially with respect to comparative performance, synergistic effects, standardization, and applicability to fields-of-use. In general, the purpose of the review is to offer a combined insight to researchers and practitioners with regard to the hydration retardation strategies and to aid the creation of more sustainable and reliable cement-based materials.
Keywords: Hydration retardation, Cement-based materials, Chemical admixtures, Natural retarders, Bio-based materials, Setting time.

1. Introduction

The performance level of cement based materials is determined by the complex interaction among chemical constituents of the material, but hydration is a significant process that affects the mechanical properties, the durability and the overall long life of the material. The knowledge of how to manipulate and retard such a hydration process has become a subject of much interest both in academic and in industrial circles particularly as the construction industry endeavors to find new ways of working in order to increase efficiency and sustainability. Since time immemorial, chemical admixtures have been used to lengthen the workability of concrete mixtures in the certain conditions and enhance the performance of concrete mixtures in a diverse range of environmental conditions [1]. The difficulty of rapid hydration during hot climate or long transportation durations has however stimulated study on alternative methods of retardation. The natural retarders are also an alternative to the use of aluminum oxide but they are based on the agricultural or bio-based materials and this is a good prospect of sustainable construction practices with both environmental and economic advantages [2] [3]. Newer synthetic compounds with lower environmental effects and greater functionalities are just emerging and are starting to change the perception of the hydration behavior in cementitious systems [4]. The importance of the research is hard to overestimate, as the environmental factor of climate and the lack of resources promote development of the construction processes and cause the tendency to resort to more environmentally friendly materials and technologies [5]. Themes of hydration retardation have a wide range of factors as described in the existing literature, including the physicochemical mechanisms involved, the performance effects of different retarders and long-term durability implications [9] [10]. Methodologies used to measure hydration retardation have also evolved with both empirical approach and sophisticated modeling used to investigate the complexity of these relationships [9] [10]. Moreover, systemic reviews have determined the key performance indicators required to determine the effectiveness of retarders, thus, the study has helped in understanding their use more comprehensively [11]. However, there are critical gaps in the literature that still exist. As an example, there is no detailed research on the performance of conventional and emerging retarders, especially in different environmental settings [12]. Synergistic interactions among various retarders and their long-term effects on the mechanical properties are still under widespread research since they may have a profound implication on the practical applications [13][14]. Furthermore, although natural retarders have a bright future, the research on this topic needs to be conducted again to standardize their application and protocols of mixing and application [15], [16]. The scalability of these options is yet another area that should be addressed since most of the promising solutions are only available in laboratories without adequate real-life applications [17], [18]. This literature review will attempt to fill these gaps with the detailed examination of the current and new strategies of hydration retardation in cement-based materials. Through comparison of existing methodologies, synthesis of results of various studies as well as possible future research avenues, the review will add to the comprehensive understanding of the hydration dynamics. Moreover, it will determine the place of chemical admixtures, natural retarders, and new substitutes in the greater context of sustainable construction, therefore, preparing the way to future research and inventions in the sphere [19], [20], [21], [22], [23], [24], [25]. By this means, it shall seek to enlighten not only the practitioner but also the researchers about effective methods of retardation but shall also promote a collaborative approach regarding how a dilemma in hydration processes may be treated. Finally, this review shall broaden our current theoretical and practical awareness concerning modern developments in the field of cement science based upon emphasis brought about regarding this matter [26], [27], [28], [29], [30].

2. Review of literature

The hydration retardation effect of cement-based material, which has been discovered, proves conceptualization and application of chemical admixtures and natural and new substitutes for admixtures to have developed with time. Original research work in this field was overshadowed by the use of traditional chemical admixtures that were critical in controlling setting time of cement. These studies indicated that lignosulfonate derivatives and sugar compounds such as Calcium Lignosulfonate would be utilized as a hydration agent involved in construction activities as a function of where latency properties were applicable [1][2]. As literature evolved with time, environmental issues and sustainability involved with using such types of chemical compounds were put in the limelight. This focus towards where natural retarders were agricultural by-product derivatives marked a beginning with new research studies being effective with less environmental implications than were being witnessed when used as a means for effective synthetic counterparts [3][4][5]. Literature of previous years signifies a rising inclination towards researchers finding novel approaches such as bio-based types and methods using nanotechnology. This has culminated in effective studies being generated with a focus on learning about retarding effect mechanisms in a more profound manner while learning about history of methods of retarding synthesized along with developments within the industry with changing standards involved with this particular field of operation associated with regulation standards involved within [9][10].This interwoven massives of researches indicate a more radical course of action through a shift towards more sustainable-creative approach to issues, rather than the traditional and synthetic approach to the job, which will result in improved performance and environmental friendliness of cement-like materials in the construction of buildings [11][12]. As such, the available literature brings to light an urgent point of intersection of technology, sustainability, and practice of the hydration retardation study. The research of hydration inhibition in cementitious materials reveals that the phenomenon is quite complex and includes the mixture of various chemical admixtures, natural factors of retardation. It is notable that the chemical admixtures such as superplasticizers and retarders are significant in the control of the setting times, the workability as well as the long-term performance of the concrete. It has been found that some of these admixtures can significantly delay the hydration processes and allow the concrete mixtures to be used under harsh environments to be utilized over an extended duration of time [1] [2]. This is induced in the literature in which after numerous studies, it is demonstrated that various chemical formulations can give the desired effects of hydration retardation [3][4]. Other than the use of synthetic solutions, natural retarders also provoke the interests of sustainable practices in cement chemistry. The literature has made the efficacy of biobased natural retarders, such as sugar derivatives and hydrocolloids, in influencing the hydration rates without influencing the structural integrity [5] [6]. The growing popularity of such organic materials is a sign to change to more environmentally friendly concrete production methods [7][8] New variations in particular those of nanotechnology are indicated as potentially proffering alternative ways of modifying the properties of cement based materials in terms of hydration. It is suggested that nanomaterials can be effective enhancers of the microstructural properties and are useful as retarders [9][10]. This hybridization between the old wisdom and the new development is a dynamic situation and such addition of the special additives does not just postpone the hydration process, but also the sustainability agenda in the building industry [11][12]. In general, most literature points towards integration of several methods of retardation leading to a requirement for comprehension regarding implications in fresh and hardened concretes more effectively. The analysis connected with hydration retardation in cement-based materials points towards several strategies employed through methods followed being of utmost importance regarding achievement of accomplishment connected with the chemical admixture and natural retarder along with several other alternatives. For example, experiments along with computational analysis help regarding data enabling effective information regarding methods being followed in accordance with chemicals affecting hydration process. This leads to capability regarding several admixture processes such as lignosulfonate along with sugar evidencing diverse effects regarding workability along with other effects regarding retardation [1], [2], [3]. Additionally, utilizing natural retarders along with experiments regarding material being used would comprise agricultural by-product evidencing additional sustainable alternatives regarding modification regarding hydration properties. This indicates that these natural alternatives would attain additional enhanced effects with less effects regarding natural earth, indicating a two-fold advantage [4], [5]. New methods regarding experiments particularly evidencing application regarding extremely analytical techniques such as nuclear magnetic resonance along with differential thermal analysis would provide additional information regarding several micro structures evidencing changes regarding hydration [6], [7]. The techniques are capable of giving the chemical interactions in the various temperature and mixture conditions a fine control needed in the investigation of how formulation variants could lead to various hydration behaviours. In addition, meta-analytical techniques involving the synthesis of the data of multiple studies have discovered the shared patterns in the implications of retardation by different forms of admixtures in linking the importance of setting in the interpretation of the results [8], [9]. In this way, the scientific explanations of the hydration retardation can be fortified by these different methodological viewpoints, which in the end can lead to the future research to be more efficient and sustainable towards cement-based materials. There is lots of debate on the performance and processes of chemical admixtures and natural retarders in alleviating hydration in cement-based materials. The different researchers arrive at the same conclusion that the hydration kinetics of chemical admixtures like lignosulfonates and other polysaccharides has a significant effect in creating complexes with calcium ions, which eventually increases the setting times [1][2]. Recent discoveries have also contributed to this point of view by showing that in addition to delaying hydration, these interactions can also be used to improve the workability of concrete mixtures, which is a two-fold advantage to construction applications [3][4]. Additionally, natural retarding agents produced using plant extracts are also being considered as studies have shown that such agents also form a more viable and effective alternative without a compromise in performance. Additionally, certain fruit and seed extracts have shown a better retarding agent effect as illustrated in [5][6]. This notion has lately stressed a transformation towards approaches that are environmentally friendly in light of the sustainability culture being practiced in construction environments [7]. On the other side of the argument exist counterarguments that exist in accordance with differences in levels of efficiency of such retarding agents depending on composition levels and levels of compositions. Certain studies have made a claim about the potential use of natural ingredients culminating in sufficient levels of retarding effect possibilities while others culminate in levels that would potentially lead to uncertainty regarding levels of effects contributed by varying environmental factors [8],[9]. This needs potential levels of uncertainties with regard to its reliance because such researchers claim that this warrants further study to better grasp more regarding levels about levels concerning chemistry involved with this standing right in the center stage of emphasis [10]. Collation of all such theoretical points of view leads towards a total insight regarding such a current scenario existing in such a hydration retarding environment in a manner describing a convergence towards a convergence of such conventional approaches with newer approaches with emphasis towards a great need towards thorough evaluations to ensure a level of uniformity with regard to such resulting levels in diverse approaches.

3. Conclusion

The discussion on hydration retardation of cement-like products can be considered as an in-depth analysis of the shifting future of chemical admixtures, natural one and the new options. Some of the important results include the inseparability between the hydration levels and the cementitious system performance, thus the significance of proper retardation measures applied in optimizing the workability, durability and performance of cementitious systems, at different environmental conditions. CaSO4 lignosulfonates and other sugars amongst other things have long been known to have a pronounced effect of increasing the duration of hydration, which is important in construction works during hot weather, or in construction work that involves logistical delay

[1][2]. At the same time, newer literature has moved to focusing on natural retarders based on agricultural by-products that, in addition to presenting comparable efficacy, also have the advantage of providing sustainability benefits due to the lack of reliance on synthetic equivalents [3][4][5]. However, apart from this focus, a new trend has begun to emerge concerning alternatives such as bio-based retarders and nanomaterials. The new approaches encompass novel mechanisms that may be used for further improvement in hydration and performance in the environment [6][7]. As indicated in this literature review, a dynamic debate has evolved among researchers regarding synergies associated with these types of retarders. This literature review indicates that a clear perception regarding how to maximize hydration associated with different regions of application has been put forward [8],[9]. A sum of available knowledge associated with this literature pertains to a possible shift towards a more integrated approach associated with a focus toward sustainable methods without reducing practical performance capability associated with construction material requirements for a high level of performance. However, one must discuss existing limitations associated with this literature. A comparison between conventional methods and newly emerging approaches for retardation remains associated with a prominent level of no comparison among environmental conditions [12][13]. This indicates a prominent level of critical deficit pertaining to this literature. This deficit may be effectively supplemented in future studies, especially those investigating long-term viability associated with synergistic approaches [14]. Moreover, though the potential of natural retarders seems to be promising, research has not yet determined standardized procedures of their application hindering their wider implementation in the industry [15], [16]. The way forward in future studies should be bridging these gaps through comparative analysis and standardisation of methods to prove the effectiveness of natural and emerging alternatives under different situations. Moreover, more attention should be paid to the scalability and applicability of these innovations in the field of activity since a large proportion of the successful laboratory results have not yet become widely implemented [17],[18]. The sustainability of the use in these retarders over long-term will be essential in the investigation process to inform the best practice in the industry [19], [20]. Finally, this literature review confirms the importance of hydration retardation measures in cement-based materials to increase the sustainability and performance of cement-based materials, which is a crucial factor as the construction sector is under increasing pressures of resource shortages and climate change [21], [22]. Having identified the complex changes in both chemical and natural retarders, scientists and professionals will be able to establish partnership and move to the further advancement of localized solutions that will help to facilitate efficiency and environmental awareness in construction operations [23], [24], [25]. The knowledge of this review will not only be used to support future research but also precondition the development of practical application that can meet the increasing needs of sustainability in the contemporary infrastructure [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [30], [40].

Table 1. Literature Review Summary

Author	Main Focus	Findings
Li (2024)	Investigate the applicability of gasification coarse slag in cement-based materials to enhance its utilization and reduce environmental risks.	Gasification coarse slag is suitable for use in cement roadbed materials, especially at a 15-20% mixing ratio, leading to improved strength after 28 days.
Wang et al. (2023)	Analyze how chemical admixtures affect the workability and	Tartaric acid significantly improves working performance; optimal dosages

	mechanical properties of self-leveling mortars.	enhance strengths and hydration behavior.
Zhang et al. (2022)	Overview of organic rheology modifiers and their impacts on the rheological behavior of cement-based materials.	Microscale interactions of high-performance superplasticizers are crucial for optimizing concrete performance.
Yang et al. (2020)	Assessing hydration dynamics using electrochemical impedance for cement mixes with mineral admixtures.	Hydration reactions varied by admixture; fly ash and slag showed distinct phases affecting strength development.
Galan et al. (2017)	Investigate the role of intrinsic anhydrite in calcium sulfoaluminate cement's performance.	Intrinsic anhydrite improves properties and sustainability prospects in new cement formulations.
Buhl et al. (2015)	Analyze how additives influence the transition from tobermorite to xonotlite in cement.	Calcium chloride enhances tobermorite formation, while sucrose adversely affects cement performance.
Arora et al. (2016)	Review advancements in magnesium-based inorganic cements and their applications.	While MgO-based cements have unique benefits, their high cost and performance limitations hinder widespread adoption.
Dvorkin et al. (2018)	Explore the use of phosphogypsum in mineral binder applications.	Neutralized phosphogypsum effectively substitutes natural gypsum and enhances cement performance.
Bayati and Aida (2019)	Optimizing geopolymer binders for downhole cement applications.	Using retarders helps manage setting times of geopolymer binders in various temperatures.
Castro-Gomes et al (2015).	Investigate how carboxylic acids affect Portland/calcium aluminate cements.	Lactic acid enhances early strength while citric acid reduces it across doses.
Aranda et al. (2015)	Review synchrotron techniques for studying cement and concrete microstructures.	These techniques enable advanced analysis of complex cementing materials.
Ji et al. (2024)	Study ion binding behavior in the hydration of Portland cement components.	Binding behavior varies significantly with hydration conditions and ion types.
Swamy (2008)	Propose durability-focused approaches in cement design.	Emphasizes designing for durability over just strength in concrete.
Trtnik et al. (2013)	Analyze superplasticizer impacts on cement paste structural formation.	Superplasticizers reduce P-wave velocity, indicating delayed solid framework formation.
Jakob et al. (2020)	Examine cement-superplasticizer incompatibility's effects on rheology.	Incompatibility can cause rapid stiffening, suggesting careful timing and additives are crucial.
Cherkaoui et al. (2012)	Study hydration and shrinkage in reactive powder concretes.	Extrudable RPC demonstrates high durability and low shrinkage potential.
De Schutter et al. (2019)	Explore structure-property relationships of polycarboxylate superplasticizers.	RAFT polymerization enables better control over PCE properties for enhanced performance.
Govin et al. (2006)	Investigate wood's effects on cement hydration.	Natural wood inhibits hydration, affecting cement paste properties and performance.
Deves et al. (2011)	Examine effects of cellulose ethers on cement mortars.	Cellulose ethers significantly impact water retention and rheological properties.

Roşca et al. (2008)	Study characteristics of concrete enhanced with chemical admixtures.	Superplasticizers improved workability and durability, optimizing concrete performance.
Al-Tabbaa et al. (2015)	Explore mechanical properties of quaternary blended cements.	Blended cements reduce shrinkage and improve long-term strength.
Tracz et al. (2025)	Assess effects of hydration and carbonation on gas permeability.	Natural carbonation reduces permeability due to microstructural changes over time.
Luo et al. (2025)	Develop a theoretical model for predicting PCE effects on hydration.	Model effectively captures PCE impacts, aiding in better admixture formulations.
Yi et al. (2024)	Investigate natural pozzolana's influence on Portland cement hydration.	Natural pozzolana enhances hydration, refines pore structure, improving concrete durability.
Dong et al. (2024)	Improve dispersibility of nano-SiO2 in cement through chemical modification.	Modified nano-SiO2 enhances hydration kinetics, improving early-age strength.
Shan et al. (2024)	Examine early hydration of hot-stuffy steel slag in cement composites.	Hot-stuffy slag enhances early hydration without retarding the cement process.
Rubinaite et al. (2023)	Evaluate hydrothermal curing effects on belite cement mortar.	Optimized curing greatly improves strength, achieving over 20 MPa at high temperatures.
Llorens et al. (2023)	Study the impact of untreated natural fibers on cement hydration.	Natural fibers enhance hydration and CO2 fixation, improving sustainability.
Kriptavičius et al. (2022)	Investigate natural zeolite and glass powder's effects on cement properties.	Optimal zeolite and glass mixtures yield improved strength and reduced porosity.
Kriptavičius (2021)	Assess the influence of natural zeolite on hydration and material properties.	Natural zeolite accelerates hydration and improves compressive strength in cement.
Petrella et al. (2021)	Characterize magnesium potassium phosphate cement for 3D printing applications.	MKPC formulations exhibit suitable properties for sustainable 3D concrete printing solutions.
Hajimohammadi and Ailar (2025)	Investigate gypsum's role in alkali-activated slag materials.	Gypsum enhances early reaction products but requires careful content optimization to address durability.
Hicks (2012)	Explore sustainable cement production using coal combustion by-products.	Utilizing these by-products can enhance cement properties and reduce ecological impact.
Fentiman and Linda (1989)	Develop a framework for decision-making for incompetent adults in health care.	Combines individual autonomy and community values in medical treatment decisions.
Almashaqbeh and Khaled (2019)	Enhance magnesium phosphate cement composites for 3D construction.	Optimized composites could support NASA's Mars and Moon habitation missions.
Jin et al. (2022)	Develop low-carbon composites using limestone calcined clay.	Enhanced properties demonstrated potential for significant carbon footprint reduction in cement applications.
Havens et al. (1978)	Develop low-void concrete by modifying traditional mix designs.	Incorporation of alternative materials improves strength and reduces permeability.
Shi et al. (2015)	Explore graphene oxide-modified pervious concrete for stormwater treatment.	Graphene oxide improved mechanical properties but reduced void ratios and infiltration rates.

De Belie et al. (2017)	Assess superabsorbent polymers' ability to mitigate cracking in concrete.	SAPs help control shrinkage, freeze/thaw effects, and improve sealing properties.

Acknowledgment

The authors would like to extend their sincere gratitude to the Libraries of Mustansiriyah University for their great assistance in obtaining access to academic resources which contributed to completing this research.

References

1. Haichao Li (2024) Study on the applicability of gasification coarse slag as admixture for cement-based materials. Volume(2825). Journal of Physics: Conference Series.
2. Yemin Wang, Jiaming Wu, Lei Su, Zizhuo Zhang, Zhenxing Wang, Tianyu Lei, Xiaolei Lu, et al. (2023) Effect of Chemical Admixtures on the Working Performance and Mechanical Properties of Cement-Based Self-Leveling Mortar. Buildings.
3. Qianqian Zhang, Jian Chen, Jiang Zhu, Yong Yang, Dongliang Zhou, Tao Wang, X. Shu, et al. (2022) Advances in Organic Rheology-Modifiers (Chemical Admixtures) and Their Effects on the Rheological Properties of Cement-Based Materials. Volume(15). Materials.
4. Zhuo Yang, Yineng Huang, Liehong Zhu, Hanwen Xu, Dingcheng Yu, Z. Hou (2020) Analysis on Electrochemical Impedance Spectroscopy of the Hydration Process of Cement-based Materials with a Large Amount of Mineral Admixture. Volume(558). IOP Conference Series: Earth and Environmental Science.
5. Galan, Isabel, Glasser, Fredrik, Imbabi, Mohammed Salah-Eldin, Jen, et al. (2017) The impact of intrinsic anhydrite in an experimental calcium sulfoaluminate cement from a novel, carbon-minimized production process.
6. Buhl, Josef-Christian, Hartmann, Andrea, Schulenberg, David (2015) Investigation of the Transition Reaction of Tobermorite to Xonotlite under Influence of Additives.
7. MEGA Engineering, Final Report on the Use of Reinforced Inorganic Cement Materials for Spark Wire and Drift Chamber Wire Frames, NASA Goddard Space Flight Center, 1987.
8. Arora A., Barde A., Bensted J., Bensted J., Berzelius J. J., Bianco Y., Borgerding J., et al. (2016) Magnesia-Based Cements: A Journey of 150 Years, and Cements for the Future?.
9. Dvorkin, Leonid, Lushnikova, Nataliya, Sonebi, Mohammed (2018) Application areas of phosphogypsum in production of mineral binders and composites based on them: a review of research results.
10. Bayati, Aida (2019) Controlling Pumpability of Geopolymers for Downhole Placement.
11. Castro-Gomes, João, Huang, Shifeng, Kastiukas, Gediminas, Saafi, et al. (2015) Effects of lactic and citric acid on early-age engineering properties of Portland/calcium aluminate blended cements.
12. Aranda MAG, Cuesta A, Glatter O, Mehta PK, Miguel A.G. Aranda, Mobilio S, Schlachter AS, et al. (2015) Recent studies of cements and concretes by synchrotron radiation crystallographic and cognate methods.
13. Ji, Yanliang, Pel, Leo, Sun, Zhenping, Zhang, et al. (2024) NMR investigations on Cl− and Na+ ion binding during the early hydration process of C3S, C3A and cement paste:A combined modelling and experimental study.
14. Swamy, R.N. (2008) Sustainable Concrete for the 21st Century Concept of Strength through Durability.
15. Trtnik, Gregor, Turk, Goran (2013) Influence of superplasticizers on the evolution of ultrasonic P-wave velocity through cement pastes at early age.
16. Jakob, Cordula, Jansen, Daniel, Neubauer, Jürgen, Pott, et al. (2020) Investigation of the Incompatibilities of Cement and Superplasticizers and Their Influence on the Rheological Behavior.
17. Cherkaoui, Khalid, Courtial, Mireille, de Noirfontaine, Marie-Noëlle, Dunstetter, et al. (2012) Extrudable Reactive Powder Concretes Hydration, shrinkage and transfer properties.
18. De Schutter, Geert, El Cheikh, Khadija, Hoogenboom, Richard, Lesage, et al. (2019) Structure-property relationships for polycarboxylate ether superplasticizers by means of RAFT polymerization.

19. Govin, Alexandre, Guyonnet, René, Peschard, Arnaud (2006) Modification of cement hydration at early ages by natural and heated wood.
20. Deves, Olivier, Govin, Alexandre, Grosseau, Philippe, Marchal, et al. (2011) Cellulose ethers influence on water retention and consistency in cement-based mortars.
21. Bogdan Roşca, P. Mihai (2008) Characteristics of Concrete with Admixtures.
22. Al-Tabbaa, A, Deng, M, Lau, et al. (2015) Deformation and mechanical properties of quaternary blended cements containing ground granulated blast furnace slag, fly ash and magnesia.
23. T. Tracz, T. Zdeb, Krzysztof Witkowski, Daniel Szkotak (2025) Influence of Hydration and Natural Carbonation Evolution on the Gas Permeability and Microstructure of Blended Cement Pastes. Volume(18). Materials.
24. Guitao Luo, Hua Li, Muyu Liu, Kunlun Li, Zongheng Tang, Hongbo Tan, Qimin Liu (2025) A novel adsorption–complexation–rheology model for PCE effects in early-age Portland cement hydration. Journal of the American Ceramic Society.
25. Liyun Yi, Dan Yang, Juhong Chen (2024) Understanding the role of natural pozzolana in regulating the early hydration reaction process and microstructure of Portland cement. Volume(32), 977 - 985. Fullerenes, Nanotubes and Carbon Nanostructures.
26. Lei Dong, Xin Shu, Qianping Ran (2024) Synthesis of nano-SiO2@PTPEG–VPA copolymer and its effects on early-age cement hydration. Volume(14), 25481 - 25489. RSC Advances.
27. Yichen Shan, Xun Wang, Shiyu Zhuang (2024) Early hydration of hot-stuffy steel slag-cement composite pastes: isothermal calorimetry and phase evolution. Volume(13), 1319 - 1329. Journal of Sustainable Cement-Based Materials.
28. D. Rubinaite, T. Dambrauskas, K. Baltakys, R. Šiaučiūnas (2023) Effect of Hydrothermal Curing on the Hydration and Strength Development of Belite Cement Mortar Containing Industrial Wastes. Sustainability.
29. J. Llorens, F. Julián, Ester Gifra, F. Espinach, J. Soler, M. Chamorro (2023) An Approach to Understanding the Hydration of Cement-Based Composites Reinforced with Untreated Natural Fibers. Sustainability.
30. Dalius Kriptavičius, G. Girskas, G. Skripkiūnas (2022) Use of Natural Zeolite and Glass Powder Mixture as Partial Replacement of Portland Cement: The Effect on Hydration, Properties and Porosity. Volume(15). Materials.
31. Dalius Kriptavičius (2021) INFLUENCE OF NATURAL ZEOLITE ON PORTLAND CEMENT HYDRATION PROCESSES AND PROPERTIES OF HARDENED CEMENT PASTE. Ceramics - Silikaty.
32. Andrea Petrella, Francesco Fiorito, Michele Notarnicola, Stelladriana Volpe, Valentino Sangiorgio (2021) Preparation and characterization of novel environmentally sustainable mortars based on magnesium potassium phosphate cement for additive manufacturing.
33. Hajimohammadi, Ailar, Kamali, Sima, Kilpimaa, Katja, Luukkonen, et al. (2025) The effect of gypsum on reaction kinetics and microstructure of alkali-activated CaO-FeOx-SiO2 slag.
34. James Hicks (2012) Utilization of Coal Combustion By-Products and Green Materials for Production of Hydraulic Cement.
35. Fentiman, Linda C. (1989) Privacy and Personhood Revisited: A New Framework for Substitute Decisionmaking for the Incompetent, Incurably Ill Adult.
36. Almashaqbeh, Hashem Khaled (2019) Decoding and Optimizing Magnesium Phosphate Binders for Additive Construction Applications.
37. Jin, Hesong, Li, Zhenlin, Liu, Jun, Tang, et al. (2022) Mechanics, hydration phase and pore development of embodied energy and carbon composites based on ultrahigh-volume low-carbon cement with limestone calcined clay.
38. Havens, James H., Rahal, Assaf S. (1978) Low-Void Concrete Mixtures.
39. Shi, Xianming, Xu, Gang (2015) Environmentally Friendly Pervious Concrete for Treating Deicer-Laden Stormwater: Phase I.
40. De Belie, Nele, Dubruel, Peter, Mignon, Arn, Snoeck, et al. (2017) Crack mitigation in concrete : superabsorbent polymers as key to success?.