ENHANCEMENT OF MECHANICAL PROPERTIES OF HIGH−VOLUME FLY ASH CONCRETE USING GLASS NANO POWDER AND EFFECTIVE MICROORGANISMS

ALI MOHAMMED AHMED SAGHIR ONAIZI

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Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

I dedicate my thesis work to my late father MOHAMMED A. ONAIZI, whose lifelong priority was to see such an accomplishment realized. My dear father did not only raise and nurture me but also taxed himself dearly over the years for our education and academic development. It is also dedicated to my mother, for whom I cannot express how grateful I am. My beloved mother has been a source of motivation and strength, showing her motherly care and support in incredible ways during all moments. A special feeling of gratitude and appreciation to my role model, my uncle, Prof. SAGHEER A. ONAIZI, who deserves the most credit for constantly sponsoring, instructing, and following up on this work. Super thanks forever. It is also to my brothers AHMED, ABDUL-RAHMAN, and all my sisters.

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ABSTRACT

The low strength at early ages poses a major challenge to cement replacement with high volume fly ash of concrete (HVFA). The attempts to address strength reduction of HVFA concrete have not yet framed as radical solutions, considering the engineering solutions and the economic cost. So, this study aimed to investigate strategies to use local waste materials, which are more abundant and less expensive, to compensate for the strength loss associated with using HVFA as cement replacement. Both glass bottle waste nano-powder (GBWNP), and effective microorganisms (EMs) may offer a promising material for increasing strength at early ages due to their availability and minimal cost. In addition, GBWNP has sufficient pozzolanic properties to assist the pozzolanic reaction that can compensate for the early age strength reduction associated with HVFA concrete. To achieve the study goals, a series of modified concrete were prepared with 50% fly ash (FA), as cement replacement, 10% EMs as mixing water replacement, and 2%, 4%, 6%, 8%, and 10% of GBWNP as nano additives. The fresh properties of the new synthesized mixes were tested in terms of slump value and fresh-state density. The hardened properties examined are mechanical strength including compressive, flexural, and split strengths at 3, 7, 28, 56, and 90 days. The modulus of elasticity and water absorption were evaluated at 28 days. To generate more knowledge about the microstructures of the new modified specimens, various technical tests, including scanning electronic microscope (SEM), the energy dispersive X-ray spectra (EDS), X-ray diffraction (XRD) and thermogravimetric analysis (TGA) at ages of 7 and 28 days. Results of the examined specimens show that the integrated addition of GBWNP and EMs significantly improves strength indexes at all the tested ages. The specimens with 10% EMs as mixing water replacement and 4% GBWNP demonstrate mechanical performance comparable with that of the control samples at almost all curing ages, whilst the mix prepared with 6% GBWNP outperformed the control mix of normal concrete at all curing ages. The microstructural analysis showed that hydration products increase, and the microstructure compactness and homogeneity enhance by inclusion both GBWNP and EMs, especially in case of the inclusion of 10% EMs and 6% GBWNP. Furthermore, a decreasing trend of calcium to silicon ratio (Ca:Si) and calcium to aluminium ratio (Ca:Al) due to the inclusion of GBWNP while an increasing trend of silicon to aluminium ratio (Si:Al) was observed, which confirm the role of GBWNP to boost FA to react faster, hence, improving strength properties. By employing fly ash and glass bottle waste, this study also seeks to contribute to the improvement of the environment by encouraging the recycling of waste in concrete sectors, providing efficient solutions to the landfill problems.

ABSTRAK

Kekuatan yang rendah pada usia awal menimbulkan cabaran besar kepada penggantian simen dalam konkrit dengan kandungan tinggi abu terbang (HVFA). Percubaan untuk menangani pengurangan kekuatan konkrit HVFA belum lagi dirangka sebagai penyelesaian radikal, memandangkan penyelesaian kejuruteraan dan kos yang ekonomi. Jadi, kajian ini bertujuan untuk menyiasat strategi untuk menggunakan bahan buangan tempatan, yang lebih banyak dan lebih murah, untuk mengimbangi kehilangan kekuatan yang berkaitan dengan penggunaan HVFA sebagai pengganti simen. Kedua-dua serbuk nano sisa botol kaca (GBWNP), dan mikroorganisma berkesan (EMs) mungkin menawarkan bahan yang menjanjikan untuk meningkatkan kekuatan pada peringkat awal umur kerana ketersediaannya dan kos yang minimum. Di samping itu, GBWNP mempunyai sifat pozzolanik yang mencukupi untuk membantu tindak balas pozzolanik yang boleh mengimbangi pengurangan kekuatan pada usia awal yang dikaitkan dengan konkrit HVFA. Untuk mencapai matlamat kajian, satu siri konkrit yang diubah suai telah disediakan dengan 50% abu terbang (FA), sebagai pengganti simen, 10% EMs sebagai pengganti bancuhan air, dan 2%, 4%, 6%, 8%, dan 10% daripada GBWNP sebagai bahan tambah nano. Sifat segar campuran tersintesis baharu ini kemudian diuji dari segi nilai kericihan dan ketumpatan dalam keadaan segar. Sifat keras yang dikaji adalah dari segi kekuatan mekanikal termasuk kekuatan mampatan, lenturan, dan tegangan pada 3, 7, 28, 56, dan 90 hari. Modulus keanjalan dan penyerapan air telah dinilai pada 28 hari. Untuk menjana lebih banyak pengetahuan tentang mikrostruktur spesimen baharu yang diubah suai, pelbagai ujian teknikal, termasuk pengimbasan elektronik mikroskop (SEM), spektrum sinar-X penyebaran tenaga (EDS), pembelauan sinar-X (XRD) dan analisis termogravimetrik (TGA) pada umur 7 dan 28 hari. Keputusan daripada spesimen yang diperiksa menunjukkan bahawa penambahan bersepadu GBWNP dan EM meningkatkan indeks kekuatan dengan ketara pada semua peringkat umur yang diuji. Spesimen dengan 10% EMs sebagai pengganti air bancuhan dan 4% GBWNP menunjukkan prestasi mekanikal yang setanding dengan sampel kawalan pada hampir semua umur pengawetan, manakala campuran yang disediakan dengan 6% GBWNP mengatasi prestasi campuran kawalan biasa konkrit pada semua peringkat umur pengawetan. Analisis mikrostruktur menunjukkan bahawa produk penghidratan meningkat, kepadatan dan keseragaman mikrostruktur bertambah dengan kemasukan kedua-dua GBWNP dan EMs, terutamanya dalam kes kemasukan 10% EMs dan 6% GBWNP. Tambahan pula, corak penurunan nisbah kalsium kepada silikon (Ca:Si) dan nisbah kalsium kepada aluminium (Ca:Al) disebabkan oleh kemasukan GBWNP manakala corak peningkatan nisbah silikon kepada aluminium (Si:Al) telah diperhatikan, yang mengesahkan peranan GBWNP untuk menggalakkan FA untuk bertindak balas dengan lebih pantas, oleh itu, meningkatkan sifat kekuatan. Dengan menggunakan abu terbang dan sisa botol kaca, kajian ini juga bertujuan untuk menyumbang kepada penambahbaikan alam sekitar dengan menggalakkan kitaran semula sisa dalam sektor konkrit, menyediakan penyelesaian yang cekap kepada masalah tapak pelupusan.

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LIST OF ABBREVIATIONS

ASTM	−	American Standards for Testing of Materials
BS EN	−	British Standard
CH	−	Calcium Hydroxide
C−A−S−H	−	Calcium Aluminate Silicate Hydrates
C−S−H	−	Calcium Silicate Hydrate
CNTs	−	Nanotubes
CNFs	−	Nanofibers
DTA	−	Differential Thermal Analysis
EDS	−	Energy-Dispersive X-Ray Spectra
EMs	−	Effective Microorganisms
FA	−	Fly Ash
HVFAC	−	High-Volume Fly Ash Concrete
GBWNPs	−	Glass Bottle waste Nano-Particles
MoE	−	Modulus of Elasticity
OPC	−	Ordinary Portland cement
TGA	−	Thermal Gravimetric Analysis
SEM	−	Scanning Electron Microscopy
XRD	−	X-ray diffraction
XRF	−	X-ray Fluorescence

LIST OF SYMBOLS

Ws	-	Dry-surface Weight
Wd	-	Oven-dried weight
ρ	-	Density
m	-	Mass of specimen
v	-	Volume of specimen
L	-	Length of specimen
H	-	Height of specimens
f_c	-	Compressive strength
P	-	Applied Load
A	-	Area of specimen
f_{ct}	-	Splitting tensile strength
f_{cf}	-	Flexural strength

CHAPTER 1

INTRODUCTION

1.1 Introduction and background of the problem

Globally, diverse concretes are still the major manufactured materials that are predominantly consumed worldwide other than water [1, 2]. Cement is a vital component in concrete production, but in recent decades many challenges facing concrete completely based on Ordinary Portland Cement (OPC) have begun to appear. As a result of the increase in the complexities of construction environments, durability became represents a concern for conventional concrete. Besides that, the environmental concerns related to cement production increase continuously, especially in terms of carbon dioxide (CO_2) footprint. In accordance with the 2015 Paris Agreement, global carbon emissions from the cement industry must be reduced by at least 16% by 2030 if Earth is to remain within 1.5 °C or 2 °C of pre-global warming [3]. However, with continuous urban land expansion, population growth and economic development, statistics indicate that global cement production will increase from the current 4.08 billion tonnes to 5 billion tonnes in the next 30 years [4]. Furthermore, in accordance with the Global Commission on the Economy and Environment, if developing countries increase their infrastructure to the current global average levels, then the construction industry will emit 470 gigatonnes of CO_2 into the atmosphere by 2050. Apart from producing massive amounts of greenhouse gases (e.g. CO_2, SO_x and NO_x emissions) and consuming high amounts of energy during the heating process, cement contributes to rapid landscape degradation, dust production during transportation, noise generation in quarries and raw material exhaustion [5]. All these conditions are major environmental issues that exert an impact on ecosystems that is critical to human well-being [6].

Conventional concrete demonstrates poor performance in hostile environments, particularly in the case of marine, coastal, and acid rain-exposed structures. Dams, concrete sidewalks, bridge posts, underground concrete foundations, and highway tunnels, especially those submerged in soil or seawater or near coasts or manufacturers that release chemical oxides, have deteriorated dramatically due to acid and sulphate attacks in recent decades. Cement-based concrete is sensitive to chemical attacks because of the calcium compounds present. In addition, the high porosity and crack ratio can encourage water and chemical ions to infiltrate into the matrix of the concrete, which can result in damage to the components of the concrete as well as corrosion of the reinforcing steel bars. In the case of the freeze-thaw cycle action, water trapped inside concrete matrix induces internal stress inside the matrix, leading to the development of further cracks. Furthermore, the enhanced microstructural instability and rapid disintegration that arise from calcium compounds dissolving rapidly in the acidic environment further complicates the situation. As a result, the chemical attack raises worries about the durability of cement-based concrete, which places a threat on a significant number of structures that are composed of concrete. As a result, the development of supplementary cementitious material-based concrete is one of the radical solutions to meet the challenges of durability.

Using a low percentage (<30%) or a high percentage (>30%) of fly ash (FA) in concrete is a pioneering move that has already approach to develop high durable concrete [7]. Even though FA has been the subject of extensive research over the past few decades, experts have found some contradictory findings regarding the mechanical and durability properties of concrete. Furthermore, the characteristics of FA vary based on the source. It is accepted that FA qualifies as an supplementary cementitious materials (SCM) and can be substituted for cement in the production of cementitious materials[8]. Several studies revealed FA enhances workability, reduces hydration heat and thermal cracking in cementitious materials at early ages, and improves the mechanical and durability properties of cementitious composites primarily at later ages[9, 10]. FA also decreases bleeding, which makes concrete more workable[11]. During the hydration process, the binder causes the concrete to shrink, where high shrinkage can lead to significant cracks in the structure of the concrete. So, the slow pozzolanic nature of FA is advantageous for shrinkage reduction[12]. Using high volumes of FA in concrete, specifically around 50% as cement replacement, reduced shrinkage by 30% [13]. On another aspect, Calcium hydroxide (CH) is considered a compound that has a high propensity to react with aggressive ions, which leads to the rapid deterioration of concrete due to a series of undesirable reactions. However, by converting CH to cementitious gels, through reacting with silica and aluminum present in FA, leads to fill pores and refine cracks, thus enhance concrete durability. Beside consumption of CH, filling pores and cracks, concrete resistance to aggressive ions penetration enhances, thus concrete durability increases [14]. However, since FA content's pozzolanic reaction is slower than OPC, high−volume fly ash (HVFA) concrete exhibits a marked decline in strength properties at early ages[7]. Even though the strength decreases at early ages, the strength gain is maintained for a significantly longer period of time compared to normal concrete [15]. That means FA requires an extended curing period to hydrate, which causes delays in the pursuance of construction applications. Overcoming the decline in strength at early ages is still a challenge, and no precise solutions have yet been framed with clear standards and limitations.

Several studies have provided various solutions to overcome the reduction in strength of HVFA at early ages. Some studies have suggested increasing the fineness of FA particles to increase its surface area, accelerating the pozzolanic reaction and forcing the fine FA particles to act as seeds and fillers [16-18]. Other studies have proposed increasing the alkalinity of the concrete mixture by adding extra lime (CH) to catalyse FA particles and make them react faster [19]. Amongst all these methods, nanomaterials have sparked the most interest due to their remarkable capability to fix concrete flaws at early ages, particularly those caused by FA. A wide range of nano-additives, such as nano-SiO_2, Al_2O_3, Fe_2O_3, Fe_3O_4, ZnO_2, ZrO_2, Cu_2O_3, CuO, $CaCO_3$, SF and CTs [20-25], have been harnessed due to their remarkable effects on improving the strength properties and durability of nano-modified concrete. Recently, the trend is to using waste materials sush as waste ceramic and glass, which have pozzolanic properties, as nanomaterials to overcome the flaws of concrete including HVFA concrete. The presence of noncrystalline aluminium and silicon (with high amorphous silica content) in pulverised glass waste from bottles makes such waste an effective pozzolanic material [26, 27]. Research on using glass bottle waste as nanomaterial additive to improve the early strength properties of cement is still insufficient. However, the studies that conducted on using glass bottle waste nano powder (GBWNP), including Huseien et al. study [28] revealed that adding glass bottle waste nano-powder exerts a positive effect on compressive, flexural and splitting tensile strengths, modulus of elasticity (MOE) and water absorption (WA). In accordance with the aforementioned studies [27-30], the improvement in strength and microstructure properties may be attributed to the pozzolanic reaction process, the production of extra C−S−H gel and the physical filling effect of pores and cracks, which reflect positively on the strength properties, homogeneity and compactness of cementitious systems.

In the last decade, the concept of self-healing concrete based on effective microorganisms (EMs) have developed. Effective microorganisms have shown a significant ability to improve concrete durability and restore the strength of damaged concrete. Besides, the EMs were also exhibited an ability to improve the strength properties even if undamaged concrete [31, 32]. Several researchers reported that incorporating 3%–15% EMs into the concrete matrix enhanced mechanical properties and microstructure at early ages [31, 33-35]. The enhancement of strength properties and microstructure at early ages was hypothesised to be due to calcite precipitation by EMs inside the matrix, increasing compressive [31, 36], splitting tensile and flexural strengths [36-38]. However, most studies that indicated the effect of microorganisms on mechanical strength were conducted on cement pastes, mortars or low-volume FA concrete. Besides, there is lack in understanding the mechanism of the EMs role in improving the strength performance of undamaged concrete. Furthermore, the investigation of the efficacy of effective microorganisms in improving the strength properties of HVFA concrete at early ages still not exist.

1.2 Problem statement

Fly ash (FA) is considered a pozzolanic material. It contains high content of silica and aluminium content that can react chemically with calcium hydroxide (CH) in presence of water to produce extra cementitious gels. However, the reactivity of silica and aluminium content embedded in FA is lower than cement particles, which means that the pozzolanic reaction of FA particles takes long time to react more than that in cement. Furthermore, the activation FA content depends on the concentration of calcium hydroxide that raise the alkalinity of concrete, thus forcing FA particle to react faster. However, when the replacement level of FA increases the calcium content decreases, thus, the CH formed by cement hydration became insufficient for activating all the FA contents to trigger pozzolanic reaction [39, 40]. Consequently, many unreacted FA particles remained in the paste, causing weaker bonds between aggregates, increasing the pore size and total porosity of the matrix, reducing mechanical strengths in consequence [19]. However, with time progress, more CH content precipitated around the unreacted FA particles, and the pozzolanic process continuous, thus the unreacted FA particles react [41]. But the long time required to reach the targeted compressive strength hinders progress in the implementation of the construction applications. Therefore, the search for cost-effective solutions to overcome the reduction associated with replacing OPC with high-volume fly ash (HVFA) has become an urgent need.

Several previous studies addressed various solutions to overcome the reduction in strength in early ages of concrete containing a high-volume fly ash such as increase the fineness of FA particles [16-18] and increasing the alkalinity of the concrete mixture by adding extra lime (CH) [19]. Among all of these methods, nanomaterials have sparked the most interest due to their remarkable ability to fix concrete flaws at early stage, particularly those caused by fly ash. However, most of the nanomaterials that have been introduced are rare or expansive to prepare. So, the utilize of local waste such as GBWNP and EMs seems to be more effective solution. Studies focusing to use GBWNP and EMs to improve the early strength properties of HVFA concrete is still not sufficient. Besides, the previous studies had examined the effect of the EMs and nanomaterials on mechanical performance of cement-based concrete separately. Thus, this research aims to improve the mechanical and microstructure properties of HVFA concrete by the integration of both glass bottle waste nano-powder and effective microorganisms.

1.3 Research Objectives

Based on the abovementioned problem statement the following objectives are set:

(a) To determine the optimum percentage of GBWNP that achieved better strength performance of HVFA concrete at early ages.

(b) To overcome the reduction in mechanical performance resulting due to replacing cement with 50% of FA by using GBWNP and EMs.

(c) To investigate the role of both GBWNP and EMs in enhancing the microstructure properties of HVFA concrete.

1.4 Research Scope and Limitation

This research (experimental) examined the influence of co-adding both glass bottle waste nano powder and effective microorganisms on the possibility of developing a new modified concrete with enhanced mechanical strength and durability. This novel modified concrete were made by combining OPC, FA, and GBWNP as binders with a mixture of tap water and EMs broth as a mixing solution. The high-volume fly ash modified concrete has been synthesized by replacing 50% of OPC with FA, that has been collected from the Tanjung Bin power station in Johor (Malaysia). Based on a literature review, fly ash as cement replacement levels of more than 50% leads to lack of calcium content, thus not guarantee achieving the target strength. Therefore, FA content has been fixed at the level of 50%. The water-cement ratio also was fixed at 0.50 to achieve a comparison purpose between the different synthesized mixes and avoid the side effects of change of w/c ratio. Similarly, based on a literature review, effective replacement levels of EMs have been indicated in the range of 5-15% of the mixed water content, so the content of the EM solution has been kept at 10 % wt. of water mixing. Then, various percentages of glass bottle waste (2, 4, 6, 8 and 10% wt. of binder) have been added to achieve the target strength between 30-40 MPa at 28 days.

The physical, chemical, and mineralogical characteristics of raw materials were determined in order to get a better understanding of their properties. The effects of co-addition of glass bottle waste nano-powder (2, 4, 6, 8 and 10% wt. of binder) and EMs on workability, mechanical properties and microstructures of synthesized modified concrete were examined, and the optimum percentage of glass bottle waste nano-powder has been determined. The proportions of the mix were calculated using the method described in Marsh (2007), also known as the Department of Environment (DOE) method. The control mix were then calibrated to achieve a compressive strength higher than 30 MPa after 28 days with a slump between 30−60 mm.

The workability of concrete was evaluated in terms of slump to provide an assessment of the ease of handling of concrete in its fresh state in accordance with ASTM C143 [42]. Compressive strength test was conducted in accordance with ASTM C109 specifications [43], and due to the compressive strength is the most critical factor in concrete, the optimal percentage of GBWNP was determined on the basis of compressive strength results. Depending on these results, the flexural strength, splitting tensile strength, modulus of elasticity (MOE) and WA tests and microstructural tests were preceded with the optimal percentage of GBWNP. Flexural strength was tested in accordance with ASTM C78 [44]. Tensile strength was evaluated in accordance with ASTM C496 [45]. MOE was examined in accordance with ASTM C469/C469M [46]. The compressive , splitting tensile, flexural strength were determined at 3, 7, 28, 56 and 90 days. The modulus of elasticity, hardened density and water absorption were determined at 28 days. Thermal Gravimetric Analysis (TGA), X-ray Diffraction (XRD), and scanning electron microscopy (SEM) measurements were used to evaluate the microstructures of the designed mixes at 7 and 28 days. In evaluating the available literature, the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM) was used. Furthermore, the findings of the study have been compared to similar research to provide further evidence of their precision.

1.5 Significance of study

As abovementioned, this research intends to generate new information on the use of glass bottle waste nano powder, which is considered widely available, inexpensive, and provides environmental solutions to reduce solid waste. Furthermore, it will contribute to the advancement of standard requirements for multi-blend modified concrete through systematic techniques of sample preparation from waste materials, suitable and meticulous materials characterizations, and subsequent data analysis. This understanding is likely to spur the development of environmentally friendly and low-cost modified concrete for a wide range of applications in the construction industry. This would be extremely beneficial to Malaysia's long-term growth, as waste disposal issues related to landfilling would be avoided and minimised. The novel findings of this study are expected to provide a foundation for future research and improved understanding of the behaviour of a multi-blend modified concrete made from waste in a cost-effective and environmentally friendly manner.

1.6 Thesis Organization

Chapter 1 provided introduction, background of the problem, problem statement, study's objectives, scope and limits, and significance of the study.

Chapter 2 conducted a thorough analysis of the available relevant literature and covered the features of modified concrete and pozzolanic materials. It also summarised prior researches on FA, EMs, and nanomaterials-based modified concrete. This chapter was also outlined the study's gaps.

Chapter 3 highlighted a thorough discussion of the materials and sample synthesis procedures, as well as the tests utilised to characterise the samples. The basic principles of several tests were emphasised, which are important for evaluating the performance of modified concrete. Furthermore, characterized the physical, mineral and chemical properties of OPC, FA, EMs, and GNP in details. The characterization of coarse and fine aggregate also provided in this chapter.

Chapter 4 presented the significant experimental outcomes and discussions on the fresh and hardened properties of modified concrete. The results of workability/slump, the compressive strength, splitting tensile, flexural strength, modulus elasticity and water absorption were presented in discussed. Moreover, the microstructures of the new designed concretes were revealed using SEM images, EDS analysis, TGA/DTA, and XRD spectra, and describing the percentage and type of hydration products for each mixture.

Chapter 5 concluded the thesis and provided some recommendations for further research in modified concrete using waste materials.

REFERENCES

1. Monteiro, P., S. Miller, and A. Horvath, *Towards sustainable concrete.* Nature Materials, 2017. **16**: p. 698-699.
2. Samadi, M., et al., *Waste ceramic as low cost and eco-friendly materials in the production of sustainable mortars.* Journal of Cleaner Production, 2020: p. 121825.
3. Watts, J., *Concrete: the most destructive material on Earth.* The Guardian, 2019. **25**: p. 1-9.
4. Preston, F. and J. Lehne, *Making Concrete Change Innovation in Low-carbon Cement and Concrete*. 2018: Chatham House - The Royal Institute of International Affairs.
5. Onaizi, A.M., et al., *Effect of nanomaterials inclusion on sustainability of cement-based concretes: A comprehensive review.* Construction and Building Materials, 2021. **306**: p. 124850.
6. Fahim Huseien, G., et al., *Geopolymer mortars as sustainable repair material: A comprehensive review.* Renewable and Sustainable Energy Reviews, 2017. **80**: p. 54-74.
7. Li, G., et al., *Fly Ash Application as Supplementary Cementitious Material: A Review.* Materials, 2022. **15**(7): p. 2664.
8. Sua-iam, G. and N. Makul, *Rheological and mechanical properties of cement–fly ash self-consolidating concrete incorporating high volumes of alumina-based material as fine aggregate.* Construction and Building Materials, 2015. **95**: p. 736-747.
9. Şahmaran, M. and V.C. Li, *Durability properties of micro-cracked ECC containing high volumes fly ash.* Cement and Concrete Research, 2009. **39**(11): p. 1033-1043.
10. Uthaman, S., et al., *Enhancement of strength and durability of fly ash concrete in seawater environments: Synergistic effect of nanoparticles.* Construction and Building Materials, 2018. **187**: p. 448-459.
11. Yao, Z., et al., *A comprehensive review on the applications of coal fly ash.* Earth-science reviews, 2015. **141**: p. 105-121.

12. Shen, D., et al., *Early-age residual stress and stress relaxation of high-performance concrete containing fly ash.* Magazine of Concrete Research, 2018. **70**(14): p. 726-738.

13. Atiş, C.D., *High-volume fly ash concrete with high strength and low drying shrinkage.* Journal of materials in civil engineering, 2003. **15**(2): p. 153-156.

14. John, E., T. Matschei, and D. Stephan, *Nucleation seeding with calcium silicate hydrate–A review.* Cement and Concrete Research, 2018. **113**: p. 74-85.

15. Saha, A.K. and P.K. Sarker, *Sustainable use of ferronickel slag fine aggregate and fly ash in structural concrete: Mechanical properties and leaching study.* Journal of Cleaner Production, 2017. **162**: p. 438-448.

16. Nath, S. and S. Kumar, *Role of particle fineness on engineering properties and microstructure of fly ash derived geopolymer.* Construction and Building Materials, 2020. **233**: p. 117294.

17. Hsu, S., M. Chi, and R. Huang, *Effect of fineness and replacement ratio of ground fly ash on properties of blended cement mortar.* Construction and Building Materials, 2018. **176**: p. 250-258.

18. Sun, Y., K. Wang, and H. Lee, *Prediction of compressive strength development for blended cement mortar considering fly ash fineness and replacement ratio.* Construction and Building Materials, 2021. **271**: p. 121532.

19. Herath, C., et al., *Performance of high volume fly ash concrete incorporating additives: A systematic literature review.* Construction and Building Materials, 2020. **258**: p. 120606.

20. Kumari, K., et al., *Nanoparticles for enhancing mechanical properties of fly ash concrete.* Materials Today: Proceedings, 2016. **3**(6): p. 2387-2393.

21. Ng, D.S., et al., *Influence of SiO2, TiO2 and Fe2O3 nanoparticles on the properties of fly ash blended cement mortars.* Construction and Building Materials, 2020. **258**: p. 119627.

22. Liu, M., H. Tan, and X. He, *Effects of nano-SiO2 on early strength and microstructure of steam-cured high volume fly ash cement system.* Construction and Building Materials, 2019. **194**: p. 350-359.

23. Rashad, A.M., *Effects of ZnO2, ZrO2, Cu2O3, CuO, CaCO3, SF, FA, cement and geothermal silica waste nanoparticles on properties of cementitious materials–A short guide for Civil Engineer.* Construction and Building Materials, 2013. **48**: p. 1120-1133.

24. Zhang, R., et al., *Influences of nano-TiO2 on the properties of cement-based materials: Hydration and drying shrinkage.* Construction and Building Materials, 2015. **81**: p. 35-41.
25. Aggarwal, P., R.P. Singh, and Y. Aggarwal, *Use of nano-silica in cement based materials—A review.* Cogent Engineering, 2015. **2**(1).
26. Samadi, M., et al., *Influence of Glass Silica Waste Nano Powder on the Mechanical and Microstructure Properties of Alkali-Activated Mortars.* Nanomaterials (Basel), 2020. **10**(2).
27. Schwarz, N., H. Cam, and N. Neithalath, *Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash.* Cement and Concrete Composites, 2008. **30**(6): p. 486-496.
28. Huseien, G.F., et al., *Alkali-activated mortars blended with glass bottle waste nano powder: Environmental benefit and sustainability.* Journal of Cleaner Production, 2020. **243**.
29. Deng, Y., et al., *Preparation and mechanical characterization of engineered cementitious composites with high-volume fly ash and waste glass powder.* Journal of Cleaner Production, 2021: p. 130222.
30. Onaizi, A.M., et al., *Effect of the addition of nano glass powder on the compressive strength of high volume fly ash modified concrete.* Materials Today: Proceedings, 2021.
31. Fahim Huseien, G., et al., *Durability performance of modified concrete incorporating fly ash and effective microorganism.* Construction and Building Materials, 2021. **267**.
32. Ismail, N. and H. Mohd Saman, *Microstructure examination and strength characteristics of effective microbed cement.* 2014.
33. Isa, M.N., M.M. Garba, and A.L. Kawu, *Influence of locally made effective microorganisms on the compressive strength of concrete.* J. of Multidisciplinary Engineering Science and Technology, 2016. **3**(4): p. 4425-4429.
34. Sato, N., et al. *Some properties of concrete mixed with effective microorganisms and the on-site investigation of the completed structures*. in *Proceedings of the 28 th International conference, Our world in concrete and structures, 28-29 August, 2003, Singapore*. 2003.

35. Sam, A.M., et al. *Fresh and hardened properties of concrete containing effective microorganisms*. in *IOP Conference Series: Earth and Environmental Science*. 2019. IOP Publishing.
36. Nain, N., et al., *Enhancement in strength parameters of concrete by application of Bacillus bacteria.* Construction and Building Materials, 2019. **202**: p. 904-908.
37. Andrew, T.C.S., I.I. Syahrizal, and M.Y. Jamaluddin. *Effective microorganisms for concrete (EMC) admixture–its effects to the mechanical properties of concrete*. in *Awam International Conference on Civil Engineering (AICCE'12) Geohazard Information Zonation (GIZ'12)*. 2012.
38. Abd Rahman, N.A. and A.R.M. Sam, *Properties of Normal Cement Concrete Containing Effective Microorganism.* 2016.
39. Feldman, R., G. Carette, and V. Malhotra, *Studies on mechanics of development of physical and mechanical properties of high-volume fly ash-cement pastes.* Cement and Concrete Composites, 1990. **12**(4): p. 245-251.
40. Berry, E., R. Hemmings, and B. Cornelius, *Mechanisms of hydration reactions in high volume fly ash pastes and mortars.* Cement and Concrete Composites, 1990. **12**(4): p. 253-261.
41. Aydin, E. and H.Ş. Arel, *Characterization of high-volume fly-ash cement pastes for sustainable construction applications.* Construction and Building Materials, 2017. **157**: p. 96-107.
42. Standard, A., *C143 (2015) Standard test method for slump of hydraulic-cement concrete.* ASTM International, West Conshohocken.
43. ASTM, A., *C109/C109M-11: Standard test method for compressive strength of hydraulic cement mortars.* American Society for Testing and Materials International, West Conshohocken, 2011.
44. ASTM, C., *78-02.* Standard test method for flexural strength of concrete (Using simple beam with third-point loading), 2002.
45. Concrete, A.I.C.C.o. and C. Aggregates, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens1*. 2017: ASTM international.
46. Standard, A., *C469/C469M-14, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.* West Conshohocken, PA: ASTM International.

47. Sahoo, S., P.K. Parhi, and B. Chandra Panda, *Durability properties of concrete with silica fume and rice husk ash.* Cleaner Engineering and Technology, 2021. **2**.
48. IEA. *Cement technology roadmap plots path to cutting CO2 emissions 24% by 2050*. 6 April 2018; Available from: https://www.iea.org/news/cement-technology-roadmap-plots-path-to-cutting-co2-emissions-24-by-2050.
49. Cao, Z., et al., *Elaborating the History of Our Cementing Societies: An in-Use Stock Perspective.* Environmental Science & Technology, 2017. **51**(19): p. 11468-11475.
50. Monteiro, P.J.M., S.A. Miller, and A. Horvath, *Towards sustainable concrete.* Nat Mater, 2017. **16**(7): p. 698-699.
51. Hossain, M., et al., *Durability of mortar and concrete containing alkali-activated binder with pozzolans: A review.* Construction and Building Materials, 2015. **93**: p. 95-109.
52. Adkins, D.F. and V.T. Christiansen, *Freeze-thaw deterioration of concrete pavements.* Journal of Materials in Civil Engineering, 1989. **1**(2): p. 97-104.
53. Ababneh, A.N., *The coupled effect of moisture diffusion, chloride penetration and freezing-thawing on concrete durability*. 2002, University of Colorado Denver.
54. Chindaprasirt, P. and U. Rattanasak, *Improvement of durability of cement pipe with high calcium fly ash geopolymer covering.* Construction and Building Materials, 2016. **112**: p. 956-961.
55. Tian, B. and M.D. Cohen, *Does gypsum formation during sulfate attack on concrete lead to expansion?* Cement and concrete research, 2000. **30**(1): p. 117-123.
56. Elahi, M.M.A. and C.R. Shearer. *Improving the sulfate attack resistance of portland-limestone cement through sulfate optimization: a calorimetry-based approach*. in *Proceedings of the 5th International Conference on Sustainable Construction Materials & Technologies, London, UK*. 2019. International Committee of the SCMT conferences, Coventry, UK.
57. Khan, H.A., et al., *Durability of calcium aluminate and sulphate resistant Portland cement based mortars in aggressive sewer environment and sulphuric acid.* Cement and Concrete Research, 2019. **124**: p. 105852.

58. Sadeghi-Nik, A., et al., *Modification of microstructure and mechanical properties of cement by nanoparticles through a sustainable development approach.* Construction and Building Materials, 2017. **155**: p. 880-891.
59. Lothenbach, B., K. Scrivener, and R. Hooton, *Supplementary cementitious materials.* Cement and concrete research, 2011. **41**(12): p. 1244-1256.
60. Siddique, R. and A. Rajor, *Use of cement kiln dust in cement concrete and its leachate characteristics.* Resources, Conservation and Recycling, 2012. **61**: p. 59-68.
61. Li, L., et al., *Reutilization of clay brick waste in mortar: Paste replacement versus cement replacement.* Journal of Materials in Civil Engineering, 2019. **31**(7): p. 04019129.
62. Miller, S.A., *Supplementary cementitious materials to mitigate greenhouse gas emissions from concrete: can there be too much of a good thing?* Journal of Cleaner Production, 2018. **178**: p. 587-598.
63. Martirena, F. and J. Monzó, *Vegetable ashes as supplementary cementitious materials.* Cement and Concrete Research, 2018. **114**: p. 57-64.
64. Fily-Paré, I., et al., *Effects of Glass Powder (GP) on the Pore Solution of Cement Pastes.* Special Publication, 2017. **320**: p. 45.1-45.12.
65. Li, X., et al., *Reactivity tests for supplementary cementitious materials: RILEM TC 267-TRM phase 1.* Materials and Structures, 2018. **51**(6): p. 1-14.
66. De Belie, N., M. Soutsos, and E. Gruyaert, *Properties of fresh and hardened concrete containing supplementary cementitious materials*. Vol. 25. 2018: Springer.
67. Juenger, M.C., R. Snellings, and S.A. Bernal, *Supplementary cementitious materials: New sources, characterization, and performance insights.* Cement and Concrete Research, 2019. **122**: p. 257-273.
68. Duchesne, J., *Alternative supplementary cementitious materials for sustainable concrete structures: a review on characterization and properties.* Waste and Biomass Valorization, 2021. **12**(3): p. 1219-1236.
69. Ismail, K.N., K. Hussin, and M.S. Idris, *Physical, chemical and mineralogical properties of fly ash.* Journal of Nuclear and Related Technology, 2007. **4**: p. 47-51.
70. Yao, Z.T., et al., *A comprehensive review on the applications of coal fly ash.* Earth-Science Reviews, 2015. **141**: p. 105-121.

71. Surabhi, S., *Fly ash in India: generation vis-à-vis utilization and Global perspective.* Int J Appl Chem, 2017. **13**(1): p. 29-52.
72. Gollakota, A.R., V. Volli, and C.-M. Shu, *Progressive utilisation prospects of coal fly ash: A review.* Science of the Total Environment, 2019. **672**: p. 951-989.
73. Blissett, R. and N. Rowson, *A review of the multi-component utilisation of coal fly ash.* Fuel, 2012. **97**: p. 1-23.
74. Vassilev, S.V. and C.G. Vassileva, *A new approach for the classification of coal fly ashes based on their origin, composition, properties, and behaviour.* Fuel, 2007. **86**(10-11): p. 1490-1512.
75. Koukouzas, N.K., et al., *Mineralogy and geochemistry of Greek and Chinese coal fly ash.* Fuel, 2006. **85**(16): p. 2301-2309.
76. Vassilev, S.V. and C.G. Vassileva, *Methods for characterization of composition of fly ashes from coal-fired power stations: a critical overview.* Energy & Fuels, 2005. **19**(3): p. 1084-1098.
77. Belviso, C., *State-of-the-art applications of fly ash from coal and biomass: A focus on zeolite synthesis processes and issues.* Progress in Energy and Combustion Science, 2018. **65**: p. 109-135.
78. Ma, J., et al., *Influence of particle morphology of ground fly ash on the fluidity and strength of cement paste.* Materials, 2021. **14**(2): p. 283.
79. Bicer, A., *Effect of fly ash particle size on thermal and mechanical properties of fly ash-cement composites.* Thermal Science and Engineering Progress, 2018. **8**: p. 78-82.
80. Panda, L. and S. Dash, *Characterization and utilization of coal fly ash: a review.* Emerging Materials Research, 2020. **9**(3): p. 921-934.
81. Song, M., P. Kaewmee, and F. Takahashi. *Mechanism analysis of modification of coal fly ash on high strength biodegradable porous composites synthesis*. in *Proceedings of the Annual Conference of Japan Society of Material Cycles and Waste Management The 29th Annual Conference of Japan Society of Material Cycles and Waste Management*. 2018. Japan Society of Material Cycles and Waste Management.
82. Amran, M., et al., *Fly ash-based eco-efficient concretes: A comprehensive review of the short-term properties.* Materials, 2021. **14**(15): p. 4264.

83. Sarkar, A., et al., *A comprehensive characterisation of fly ash from a thermal power plant in Eastern India.* Fuel Processing Technology, 2006. **87**(3): p. 259-277.
84. Ramyar, K. and G. Inan, *Sodium sulfate attack on plain and blended cements.* Building and environment, 2007. **42**(3): p. 1368-1372.
85. Sumer, M., *Compressive strength and sulfate resistance properties of concretes containing Class F and Class C fly ashes.* Construction and Building Materials, 2012. **34**: p. 531-536.
86. Salloum, T., *Effect of fly ash replacement on alkali and sulphate resistance of mortars*. 2007, Concordia University.
87. Dhole, R., et al., *Characterization of Fly Ashes for Sulfate Resistance.* ACI Materials Journal, 2013. **110**(2).
88. Mirvalad, S. and M. Nokken, *Minimum SCM requirements in mixtures containing limestone cement to control thaumasite sulfate attack.* Construction and Building Materials, 2015. **84**: p. 19-29.
89. Liu, K., et al., *Long-term performance of blended cement paste containing fly ash against sodium sulfate attack.* Journal of Materials in Civil Engineering, 2018. **30**(12): p. 04018309.
90. Theerawat, S., *Effect of finenesses of fly ash on expansion of mortars in magnesium sulfate.* 2006.
91. Szarek, Ł. and M. Wojtkowska, *Properties of fly ash from thermal treatment of municipal sewage sludge in terms of EN 450-1.* Archives of Environmental Protection, 2018. **44**(1).
92. Robl, T., *Ash beneficiation, quality, and standard criteria*, in *Coal Combustion Products (CCP's)*. 2017, Elsevier. p. 217-224.
93. Zunino, F., D.P. Bentz, and J. Castro, *Reducing setting time of blended cement paste containing high-SO3 fly ash (HSFA) using chemical/physical accelerators and by fly ash pre-washing.* Cement and Concrete Composites, 2018. **90**: p. 14-26.
94. Suraneni, P., et al., *ASTM C618 fly ash specification: Comparison with other specifications, shortcomings, and solutions.* ACI Mater. J, 2021. **118**: p. 157-167.

95. ASTM, C., *C618-15, Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.* West Conshohocken: ASTM International, 2015.
96. Nath, P. and P. Sarker, *Effect of fly ash on the durability properties of high strength concrete.* Procedia Engineering, 2011. **14**: p. 1149-1156.
97. De Maeijer, P.K., et al., *Effect of ultra-fine fly ash on concrete performance and durability.* Construction and Building Materials, 2020. **263**: p. 120493.
98. Hemalatha, T. and A. Ramaswamy, *A review on fly ash characteristics–Towards promoting high volume utilization in developing sustainable concrete.* Journal of cleaner production, 2017. **147**: p. 546-559.
99. Chindaprasirt, P., et al., *Mechanical properties, chloride resistance and microstructure of Portland fly ash cement concrete containing high volume bagasse ash.* Journal of Building Engineering, 2020. **31**: p. 101415.
100. Du, S., Q. Zhao, and X. Shi, *High-Volume Fly Ash-Based Cementitious Composites as Sustainable Materials: An Overview of Recent Advances.* Advances in Civil Engineering, 2021. **2021**.
101. Choi, S.J., S.S. Lee, and P.J. Monteiro, *Effect of fly ash fineness on temperature rise, setting, and strength development of mortar.* Journal of materials in civil engineering, 2012. **24**(5): p. 499-505.
102. Uysal, M. and V. Akyuncu, *Durability performance of concrete incorporating Class F and Class C fly ashes.* Construction and Building Materials, 2012. **34**: p. 170-178.
103. Alaka, H.A. and L.O. Oyedele, *High volume fly ash concrete: The practical impact of using superabundant dose of high range water reducer.* Journal of Building Engineering, 2016. **8**: p. 81-90.
104. Moffatt, E.G., M.D. Thomas, and A. Fahim, *Performance of high-volume fly ash concrete in marine environment.* Cement and Concrete Research, 2017. **102**: p. 127-135.
105. Siddique, R. and M.I. Khan, *Fly ash*, in *Supplementary cementing materials*. 2011, Springer. p. 1-66.
106. Supit, S.W.M. and F.U.A. Shaikh, *Durability properties of high volume fly ash concrete containing nano-silica.* Materials and structures, 2015. **48**(8): p. 2431-2445.

107. Marthong, C. and T. Agrawal, *Effect of fly ash additive on concrete properties.* International Journal of Engineering Research and Applications, 2012. **2**(4): p. 1986-1991.

108. Giergiczny, Z., *Fly ash and slag.* Cement and Concrete Research, 2019. **124**: p. 105826.

109. Sun, J., et al., *Compressive strength and hydration characteristics of high-volume fly ash concrete prepared from fly ash.* Journal of Thermal Analysis and Calorimetry, 2019. **136**(2): p. 565-580.

110. Soroushian, P. and T. Ghebrab, *Field investigation of high-volume fly ash pavement concrete.* Resources, conservation and recycling, 2013. **73**: p. 78-85.

111. Duran-Herrera, A., et al., *Evaluation of sustainable high-volume fly ash concretes.* Cement and Concrete Composites, 2011. **33**(1): p. 39-45.

112. Bentz, D.P., et al., *Influence of particle size distributions on yield stress and viscosity of cement–fly ash pastes.* Cement and Concrete Research, 2012. **42**(2): p. 404-409.

113. De la Varga, I., et al., *Evaluating the hydration of high volume fly ash mixtures using chemically inert fillers.* Construction and Building Materials, 2018. **161**: p. 221-228.

114. Yang, T., et al., *Effect of fly ash microsphere on the rheology and microstructure of alkali-activated fly ash/slag pastes.* Cement and Concrete Research, 2018. **109**: p. 198-207.

115. Kim, J.H., N. Noemi, and S.P. Shah, *Effect of powder materials on the rheology and formwork pressure of self-consolidating concrete.* Cement and Concrete Composites, 2012. **34**(6): p. 746-753.

116. De Matos, P.R., M. Foiato, and L.R. Prudêncio Jr, *Ecological, fresh state and long-term mechanical properties of high-volume fly ash high-performance self-compacting concrete.* Construction and Building Materials, 2019. **203**: p. 282-293.

117. Ponikiewski, T. and J. Gołaszewski, *The influence of high-calcium fly ash on the properties of fresh and hardened self-compacting concrete and high performance self-compacting concrete.* Journal of Cleaner Production, 2014. **72**: p. 212-221.

118. Siddique, R., *Performance characteristics of high-volume Class F fly ash concrete.* Cement and Concrete Research, 2004. **34**(3): p. 487-493.

119. Burden, D., *The durability of concrete containing high levels of fly ash*. 2006, University of New Brunswick, Department of Civil Engineering.

120. Bouzoubaa, N., et al., *Mechanical properties and durability characteristics of high-volume fly ash concrete made with ordinary Portland cement and blended Portland fly ash cement.* Special Publication, 2007. **242**: p. 303-320.

121. Kumar, B., G. Tike, and P. Nanda, *Evaluation of properties of high-volume fly-ash concrete for pavements.* Journal of Materials in Civil Engineering, 2007. **19**(10): p. 906-911.

122. Balakrishnan, B. and A. Awal, *Durability properties of concrete containing high volume Malaysian fly ash.* Measurement, 2014. **2**(2.94): p. 2.94.

123. Mukherjee, S., S. Mandal, and U. Adhikari, *Comparative study on physical and mechanical properties of high slump and zero slump high volume fly ash concrete (HVFAC).* Global NEST J, 2013. **20**(10): p. 1-7.

124. Sivasundaram, V., G. Carette, and V. Malhotra, *Long-term strength development of high-volume fly ash concrete.* Cement and Concrete Composites, 1990. **12**(4): p. 263-270.

125. Berry, E.E., et al., *Hydration in high-volume fly ash concrete binders.* Materials Journal, 1994. **91**(4): p. 382-389.

126. Huang, C.-H., et al., *Mix proportions and mechanical properties of concrete containing very high-volume of Class F fly ash.* Construction and Building Materials, 2013. **46**: p. 71-78.

127. Sanchez, F. and K. Sobolev, *Nanotechnology in concrete – A review.* Construction and Building Materials, 2010. **24**(11): p. 2060-2071.

128. Abdoli, H., et al., *Effect of high energy ball milling on compressibility of nanostructured composite powder.* Powder metallurgy, 2011. **54**(1): p. 24-29.

129. Jankowska, E. and W. Zatorski. *Emission of nanosize particles in the process of nanoclay blending*. in *2009 Third International Conference on Quantum, Nano and Micro Technologies*. 2009. IEEE.

130. Sanchez, F. and K. Sobolev, *Nanotechnology in concrete–a review.* Construction and building materials, 2010. **24**(11): p. 2060-2071.

131. Bhatia, S., *Nanoparticles Types, Classification, Characterization, Fabrication Methods and Drug Delivery Applications*, in *Natural Polymer Drug Delivery Systems*. 2016. p. 33-93.

132. Shah, K.W. and G.F. Huseien, *Inorganic nanomaterials for fighting surface and airborne pathogens and viruses.* Nano Express, 2020. **1**(3).
133. Pacheco-Torgal, F. and S. Jalali, *Nanotechnology: Advantages and drawbacks in the field of construction and building materials.* Construction and Building Materials, 2011. **25**(2): p. 582-590.
134. Gajanan, K. and S. Tijare, *Applications of nanomaterials.* Materials Today: Proceedings, 2018. **5**(1): p. 1093-1096.
135. Fulekar, M., *Nanotechnology: importance and applications*. 2010: IK International Pvt Ltd.
136. Gajanan, K. and S.N. Tijare, *Applications of nanomaterials.* Materials Today: Proceedings, 2018. **5**(1, Part 1): p. 1093-1096.
137. Jones, W., et al., *Nanomaterials in construction – what is being used, and where?* Proceedings of the Institution of Civil Engineers - Construction Materials, 2019. **172**(2): p. 49-62.
138. Lin, C.-C. and W.-Y. Chen, *Effect of paint composition, nano-metal types and substrate on the improvement of biological resistance on paint finished building material.* Building and Environment, 2017. **117**: p. 49-59.
139. Shah, K.W. and Y. Lu, *Morphology, large scale synthesis and building applications of copper nanomaterials.* Construction and Building Materials, 2018. **180**: p. 544-578.
140. Zhang, X., et al., *Design of glass fiber reinforced plastics modified with CNT and pre-stretching fabric for potential sports instruments.* Materials & Design, 2016. **92**: p. 621-631.
141. Norhasri, M.M., M. Hamidah, and A.M. Fadzil, *Applications of using nano material in concrete: A review.* Construction and Building Materials, 2017. **133**: p. 91-97.
142. Papadaki, D., G. Kiriakidis, and T. Tsoutsos, *Applications of nanotechnology in construction industry*, in *Fundamentals of Nanoparticles*. 2018. p. 343-370.
143. Kewalramani, M.A. and Z.I. Syed, *Application of nanomaterials to enhance microstructure and mechanical properties of concrete.* International Journal of Integrated Engineering, 2018. **10**(2).
144. Rajak, M.A.A., Z.A. Majid, and M. Ismail, *Morphological characteristics of hardened cement pastes incorporating nano-palm oil fuel ash.* Procedia Manufacturing, 2015. **2**: p. 512-518.

145. Li, G., *Properties of high-volume fly ash concrete incorporating nano-SiO2.* Cement and Concrete research, 2004. **34**(6): p. 1043-1049.
146. Ghafari, E., et al., *The effect of nanosilica addition on flowability, strength and transport properties of ultra high performance concrete.* Materials & Design, 2014. **59**: p. 1-9.
147. Seifan, M., S. Mendoza, and A. Berenjian, *Mechanical properties and durability performance of fly ash based mortar containing nano- and micro-silica additives.* Construction and Building Materials, 2020. **252**.
148. Khaloo, A., M.H. Mobini, and P. Hosseini, *Influence of different types of nano-SiO2 particles on properties of high-performance concrete.* Construction and Building Materials, 2016. **113**: p. 188-201.
149. Mostafa, S.A., et al., *Influence of nanoparticles from waste materials on mechanical properties, durability and microstructure of UHPC.* Materials, 2020. **13**(20): p. 4530.
150. Joshaghani, A., et al., *Effects of nano-TiO2, nano-Al2O3, and nano-Fe2O3 on rheology, mechanical and durability properties of self-consolidating concrete (SCC): An experimental study.* Construction and Building Materials, 2020. **245**.
151. Adak, D., M. Sarkar, and S. Mandal, *Effect of nano-silica on strength and durability of fly ash based geopolymer mortar.* Construction and Building Materials, 2014. **70**: p. 453-459.
152. Li, Z., et al., *Investigations on the preparation and mechanical properties of the nano-alumina reinforced cement composite.* Materials Letters, 2006. **60**(3): p. 356-359.
153. Nazari, A., et al., *Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete.* Journal of American Science, 2010. **6**(5): p. 6-9.
154. Nazari, A., et al., *Mechanical properties of cement mortar with Al2O3 nanoparticles.* Journal of American Science, 2010. **6**(4): p. 94-97.
155. Hase, B. and V. Rathi, *Properties of high strength concrete incorporating colloidal nano-Al2O3.* Int J Innov Res Sci Eng Technol, 2015. **4**(3): p. 959-963.

156. Behfarnia, K. and N. Salemi, *The effects of nano-silica and nano-alumina on frost resistance of normal concrete.* Construction and Building Materials, 2013. **48**: p. 580-584.
157. Phoo-ngernkham, T., et al., *The effect of adding nano-SiO2 and nano-Al2O3 on properties of high calcium fly ash geopolymer cured at ambient temperature.* Materials & Design, 2014. **55**: p. 58-65.
158. Massa, M.A., et al., *Synthesis of new antibacterial composite coating for titanium based on highly ordered nanoporous silica and silver nanoparticles.* Materials Science and Engineering: C, 2014. **45**: p. 146-153.
159. Li, H., M.-h. Zhang, and J.-p. Ou, *Abrasion resistance of concrete containing nano-particles for pavement.* Wear, 2006. **260**(11-12): p. 1262-1266.
160. Li, H., M.-h. Zhang, and J.-p. Ou, *Flexural fatigue performance of concrete containing nano-particles for pavement.* International Journal of fatigue, 2007. **29**(7): p. 1292-1301.
161. Sorathiya, J., S. Shah, and S. Kacha, *Effect on Addition of Nano "Titanium Dioxide" (TiO2)on Compressive Strength of Cementitious Concrete.* 2018. **1**: p. 219-211.
162. Jayapalan, A., B. Lee, and K. Kurtis, *Effect of nano-sized titanium dioxide on early age hydration of Portland cement*, in *Nanotechnology in construction 3*. 2009, Springer. p. 267-273.
163. Morsy, M., S. Alsayed, and M. Aqel, *Hybrid effect of carbon nanotube and nano-clay on physico-mechanical properties of cement mortar.* Construction and Building Materials, 2011. **25**(1): p. 145-149.
164. Stynoski, P., P. Mondal, and C. Marsh, *Effects of silica additives on fracture properties of carbon nanotube and carbon fiber reinforced Portland cement mortar.* Cement and Concrete Composites, 2015. **55**: p. 232-240.
165. Mohamed, A.M., *Influence of nano materials on flexural behavior and compressive strength of concrete.* HBRC journal, 2016. **12**(2): p. 212-225.
166. Beigi, M.H., et al., *An experimental survey on combined effects of fibers and nanosilica on the mechanical, rheological, and durability properties of self-compacting concrete.* Materials & Design, 2013. **50**: p. 1019-1029.
167. Liu, Z.G., et al. *Piezoresistive Properties of cement mortar with carbon nanotube*. in *Advanced Materials Research*. 2011. Trans Tech Publ.

168. Konsta-Gdoutos, M.S., Z.S. Metaxa, and S.P. Shah, *Highly dispersed carbon nanotube reinforced cement based materials.* Cement and Concrete Research, 2010. **40**(7): p. 1052-1059.

169. Folli, A., et al., *TiO2 photocatalysis in cementitious systems: Insights into self-cleaning and depollution chemistry*. Cement and concrete research, 2012. **42**(3): p. 539-548.

170. Mudimela, P.R., et al., *Synthesis of carbon nanotubes and nanofibers on silica and cement matrix materials.* Journal of Nanomaterials, 2009. **2009**.

171. Zhang, M.-H. and J. Islam, *Use of nano-silica to reduce setting time and increase early strength of concretes with high volumes of fly ash or slag.* Construction and Building Materials, 2012. **29**: p. 573-580.

172. Said, A.M., et al., *Properties of concrete incorporating nano-silica.* Construction and Building Materials, 2012. **36**: p. 838-844.

173. Land, G. and D. Stephan, *The influence of nano-silica on the hydration of ordinary Portland cement.* Journal of materials science, 2012. **47**(2): p. 1011-1017.

174. Land, G. and D. Stephan, *Controlling cement hydration with nanoparticles.* Cement and Concrete Composites, 2015. **57**: p. 64-67.

175. Gao, K., et al., *Effects of nano-SiO2 on setting time and compressive strength of alkaliactivated metakaolin-based geopolymer.* The Open Civil Engineering Journal, 2013. **7**(1).

176. Qing, Y., et al., *Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume.* Construction and building materials, 2007. **21**(3): p. 539-545.

177. Mukharjee, B.B. and S.V. Barai, *Assessment of the influence of Nano-Silica on the behavior of mortar using factorial design of experiments.* Construction and Building Materials, 2014. **68**: p. 416-425.

178. Palla, R., et al., *High strength sustainable concrete using silica nanoparticles.* Construction and Building Materials, 2017. **138**: p. 285-295.

179. Wang, L., H. Zhang, and Y. Gao, *Effect of TiO2 Nanoparticles on Physical and Mechanical Properties of Cement at Low Temperatures.* Advances in Materials Science and Engineering, 2018. **2018**: p. 1-12.

180. Liu, J., et al., *Effects of zinc oxide nanoparticles on early-age hydration and the mechanical properties of cement paste.* Construction and Building Materials, 2019. **217**: p. 352-362.

181. Gopalakrishnan, R. and S. Nithiyanantham, *Effect of ZnO nanoparticles on cement mortar for enhancing the physico-chemical, mechanical and related properties.* Advanced Science, Engineering and Medicine, 2020. **12**(3): p. 348-355.

182. Duan, P., et al., *Effects of adding nano-TiO2 on compressive strength, drying shrinkage, carbonation and microstructure of fluidized bed fly ash based geopolymer paste.* Construction and Building Materials, 2016. **106**: p. 115-125.

183. Kontoleontos, F., et al., *Influence of colloidal nanosilica on ultrafine cement hydration: Physicochemical and microstructural characterization.* Construction and building materials, 2012. **35**: p. 347-360.

184. Mirgozar Langaroudi, M.A. and Y. Mohammadi, *Effect of nano-clay on workability, mechanical, and durability properties of self-consolidating concrete containing mineral admixtures.* Construction and Building Materials, 2018. **191**: p. 619-634.

185. Nazari, A. and S. Riahi, *Improvement compressive strength of concrete in different curing media by Al2O3 nanoparticles.* Materials Science and Engineering: A, 2011. **528**(3): p. 1183-1191.

186. Nazari, A., et al., *Benefits of Fe2O3 nanoparticles in concrete mixing matrix.* Journal of American Science, 2010. **6**(4): p. 102-106.

187. Nazari, A., et al., *The effects of incorporation Fe2O3 nanoparticles on tensile and flexural strength of concrete.* Journal of American Science, 2010. **6**(4): p. 90-93.

188. Deb, P.S., P.K. Sarker, and S. Barbhuiya, *Sorptivity and acid resistance of ambient-cured geopolymer mortars containing nano-silica.* Cement and Concrete Composites, 2016. **72**: p. 235-245.

189. Chindaprasirt, P., et al., *Effect of SiO2 and Al2O3 on the setting and hardening of high calcium fly ash-based geopolymer systems.* Journal of Materials Science, 2012. **47**(12): p. 4876-4883.

190. Aggarwal, P., R.P. Singh, and Y. Aggarwal, *Use of nano-silica in cement based materials—A review.* Cogent Engineering, 2015. **2**(1): p. 1078018.

191. Reches, Y., *Nanoparticles as concrete additives: Review and perspectives.* Construction and Building Materials, 2018. **175**: p. 483-495.

192. Li, X., et al., *Effects of graphene oxide agglomerates on workability, hydration, microstructure and compressive strength of cement paste.* Construction and Building Materials, 2017. **145**: p. 402-410.

193. Gowda, R., et al., *Effect of nano-alumina on workability, compressive strength and residual strength at elevated temperature of Cement Mortar.* Materials Today: Proceedings, 2017. **4**(11): p. 12152-12156.

194. Gao, X., Q.L. Yu, and H.J.H. Brouwers, *Characterization of alkali activated slag–fly ash blends containing nano-silica.* Construction and Building Materials, 2015. **98**: p. 397-406.

195. Nazari, A. and S. Riahi, *RETRACTED: Al2O3 nanoparticles in concrete and different curing media.* Energy and Buildings, 2011. **43**(6): p. 1480-1488.

196. Hosseini, P., A. Booshehrian, and A. Madari, *Developing concrete recycling strategies by utilization of nano-SiO 2 particles.* Waste and Biomass Valorization, 2011. **2**(3): p. 347-355.

197. Jalal, M., et al., *Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete.* Construction and Building Materials, 2015. **94**: p. 90-104.

198. Collepardi, M., et al. *Influence of amorphous colloidal silica on the properties of self-compacting concretes*. in *Proceedings of the International Conference" Challenges in Concrete Construction-Innovations and Developments in Concrete Materials and Construction", Dundee, Scotland, UK*. 2002.

199. Sumesh, M., et al., *Incorporation of nano-materials in cement composite and geopolymer based paste and mortar – A review.* Construction and Building Materials, 2017. **148**: p. 62-84.

200. Vikulin, V.V., M.K. Alekseev, and I.L. Shkarupa, *Study of the effect of some commercially available nanopowders on the strength of concrete based on alumina cement.* Refractories and Industrial Ceramics, 2011. **52**(4): p. 288-290.

201. Rashad, A.M., *A synopsis about the effect of nano-Al2O3, nano-Fe2O3, nano-Fe3O4 and nano-clay on some properties of cementitious materials–A short guide for Civil Engineer.* Materials & Design (1980-2015), 2013. **52**: p. 143-157.

202. Wang, L., et al., *Effect of Nano-SiO(2) on the Hydration and Microstructure of Portland Cement.* Nanomaterials (Basel), 2016. **6**(12).
203. Khotbehsara, M.M., et al., *Effect of nano-CuO and fly ash on the properties of self-compacting mortar.* Construction and Building Materials, 2015. **94**: p. 758-766.
204. Nazari, A. and S. Riahi, *The effects of SiO2 nanoparticles on physical and mechanical properties of high strength compacting concrete.* Composites Part B: Engineering, 2011. **42**(3): p. 570-578.
205. Lim, N.H.A.S., et al., *Microstructure and strength properties of mortar containing waste ceramic nanoparticles.* Arabian Journal for Science and Engineering, 2018. **43**(10): p. 5305-5313.
206. Zhang, A., et al., *Comparative study on the effects of nano-SiO2, nano-Fe2O3 and nano-NiO on hydration and microscopic properties of white cement.* Construction and Building Materials, 2019. **228**: p. 116767.
207. Adak, D., M. Sarkar, and S. Mandal, *Structural performance of nano-silica modified fly-ash based geopolymer concrete.* Construction and Building Materials, 2017. **135**: p. 430-439.
208. Li, H., et al., *Microstructure of cement mortar with nano-particles.* Composites Part B: Engineering, 2004. **35**(2): p. 185-189.
209. Praveenkumar, T.R., M.M. Vijayalakshmi, and M.S. Meddah, *Strengths and durability performances of blended cement concrete with TiO2 nanoparticles and rice husk ash.* Construction and Building Materials, 2019. **217**: p. 343-351.
210. Bodnarova, L. and T. Jarolim. *Study the effect of carbon nanoparticles in concrete*. in *IOP Conference Series: Materials Science and Engineering*. 2018. IOP Publishing.
211. Madandoust, R., et al., *An experimental investigation on the durability of self-compacting mortar containing nano-SiO2, nano-Fe2O3 and nano-CuO.* Construction and Building Materials, 2015. **86**: p. 44-50.
212. Khoshakhlagh, A., A. Nazari, and G. Khalaj, *Effects of Fe2O3 Nanoparticles on Water Permeability and Strength Assessments of High Strength Self-Compacting Concrete.* Journal of Materials Science & Technology, 2012. **28**(1): p. 73-82.
213. Saleh, N.J., R.I. Ibrahim, and A.D. Salman, *Characterization of nano-silica prepared from local silica sand and its application in cement mortar using*

optimization technique. Advanced Powder Technology, 2015. **26**(4): p. 1123-1133.

214. Zhang, S.-L., et al., *Effect of a novel hybrid TiO2-graphene composite on enhancing mechanical and durability characteristics of alkali-activated slag mortar.* Construction and Building Materials, 2021. **275**.

215. Abbasi, S.M., et al., *Microstructure and mechanical properties of a metakaolinite-based geopolymer nanocomposite reinforced with carbon nanotubes.* Ceramics International, 2016. **42**(14): p. 15171-15176.

216. Zhang, M.-h. and H. Li, *Pore structure and chloride permeability of concrete containing nano-particles for pavement.* Construction and Building Materials, 2011. **25**(2): p. 608-616.

217. Mohseni, E., et al., *Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina.* Construction and Building Materials, 2016. **111**: p. 429-439.

218. Beigi, M.H., et al., *An experimental survey on combined effects of fibers and nanosilica on the mechanical, rheological, and durability properties of self-compacting concrete.* Materials & Design, 2013. **50**: p. 1019-1029.

219. Shekari, A.H. and M.S. Razzaghi, *Influence of Nano Particles on Durability and Mechanical Properties of High Performance Concrete.* Procedia Engineering, 2011. **14**: p. 3036-3041.

220. Hosan, A. and F.U.A. Shaikh, *Influence of nano silica on compressive strength, durability, and microstructure of high-volume slag and high-volume slag–fly ash blended concretes.* Structural Concrete, 2020. **22**(S1).

221. Revathy, J., P. Gajalakshmi, and M. Aseem Ahmed, *Flowable nano SiO2 based cementitious mortar for ferrocement jacketed column.* Materials Today: Proceedings, 2020. **22**: p. 836-842.

222. Potapov, V., et al., *Effect of hydrothermal nanosilica on the performances of cement concrete.* Construction and Building Materials, 2021. **269**.

223. Behzadian, R. and H. Shahrajabian, *Experimental Study of the Effect of Nano-silica on the Mechanical Properties of Concrete/PET Composites.* KSCE Journal of Civil Engineering, 2019. **23**(8): p. 3660-3668.

224. Abd Elrahman, M., et al., *Influence of Nanosilica on Mechanical Properties, Sorptivity, and Microstructure of Lightweight Concrete.* Materials (Basel), 2019. **12**(19).

225. Zhang, A., et al., *Effects of nano-SiO2 and nano-Al2O3 on mechanical and durability properties of cement-based materials: A comparative study.* Journal of Building Engineering, 2021. **34**.

226. Ma, B., et al., *Effects of Nano-TiO2on the Toughness and Durability of Cement-Based Material.* Advances in Materials Science and Engineering, 2015. **2015**: p. 1-10.

227. Idrees, M., et al., *Improvement in compressive strength of Styrene-Butadiene-Rubber (SBR) modified mortars by using powder form and nanoparticles.* Journal of Building Engineering, 2021. **44**.

228. Wu, Z., et al., *Mechanisms underlying the strength enhancement of UHPC modified with nano-SiO2 and nano-CaCO3.* Cement and Concrete Composites, 2021. **119**.

229. Alex, A.G., T. Gebrehiwet, and Z. Kemal, *M-Sand cement mortar with partial replacement of alpha phase nano alumina.* Journal of Building Pathology and Rehabilitation, 2021. **6**(1).

230. Najafi Kani, E., et al., *The effects of Nano-Fe2O3 on the mechanical, physical and microstructure of cementitious composites.* Construction and Building Materials, 2021. **266**.

231. Fallah, S. and M. Nematzadeh, *Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume.* Construction and Building Materials, 2017. **132**: p. 170-187.

232. Jalal, M., et al., *Mechanical, rheological, durability and microstructural properties of high performance self-compacting concrete containing SiO2 micro and nanoparticles.* Materials & Design, 2012. **34**: p. 389-400.

233. Heikal, M., M.E.A. Zaki, and S.M. Ibrahim, *Characterization, hydration, durability of nano-Fe2O3-composite cements subjected to sulphates and chlorides media.* Construction and Building Materials, 2021. **269**.

234. Kamali, M. and A. Ghahremaninezhad, *Effect of glass powders on the mechanical and durability properties of cementitious materials.* Construction and Building Materials, 2015. **98**: p. 407-416.

235. Hama, S.M., *Improving mechanical properties of lightweight Porcelanite aggregate concrete using different waste material.* International Journal of Sustainable Built Environment, 2017. **6**(1): p. 81-90.

236. Li, Z., et al., *Effect of nano-titanium dioxide on mechanical and electrical properties and microstructure of reactive powder concrete.* Materials Research Express, 2017. **4**(9): p. 095008.
237. Faried, A.S., et al., *Mechanical and durability properties of ultra-high performance concrete incorporated with various nano waste materials under different curing conditions.* Journal of Building Engineering, 2021. **43**.
238. Kaur, M., J. Singh, and M. Kaur, *Microstructure and strength development of fly ash-based geopolymer mortar: Role of nano-metakaolin.* Construction and Building Materials, 2018. **190**: p. 672-679.
239. Nuaklong, P., V. Sata, and P. Chindaprasirt, *Properties of metakaolin-high calcium fly ash geopolymer concrete containing recycled aggregate from crushed concrete specimens.* Construction and Building Materials, 2018. **161**: p. 365-373.
240. Gunasekara, C., et al., *Effect of nano-silica addition into high volume fly ash–hydrated lime blended concrete.* Construction and Building Materials, 2020. **253**: p. 119205.
241. Hou, P.-k., et al., *Effects of colloidal nanosilica on rheological and mechanical properties of fly ash–cement mortar.* Cement and Concrete Composites, 2013. **35**(1): p. 12-22.
242. Shaikh, F., S. Supit, and P. Sarker, *A study on the effect of nano silica on compressive strength of high volume fly ash mortars and concretes.* Materials & Design, 2014. **60**: p. 433-442.
243. Roychand, R., et al., *High volume fly ash cement composite modified with nano silica, hydrated lime and set accelerator.* Materials and Structures, 2016. **49**(5): p. 1997-2008.
244. Li, H.-D., et al., *Multi-scale improved damping of high-volume fly ash cementitious composite: combined effects of polyvinyl alcohol fiber and graphene oxide.* Construction and Building Materials, 2020. **260**: p. 119901.
245. Rashad, A.M., *An exploratory study on high-volume fly ash concrete incorporating silica fume subjected to thermal loads.* Journal of Cleaner Production, 2015. **87**: p. 735-744.
246. Sun, X., et al., *Modification of high-volume fly ash cement with metakaolin for its utilization in cemented paste backfill: The effects of metakaolin content and particle size.* Powder Technology, 2021. **393**: p. 539-549.

247. Zhou, Z., et al., *Microstructural investigation of high-volume fly ash composites containing nano-calcium silicate hydrate crystals.* Journal of Materials in Civil Engineering, 2021. **33**(12): p. 04021356.
248. Velandia, D.F., et al., *Evaluation of activated high volume fly ash systems using Na2SO4, lime and quicklime in mortars with high loss on ignition fly ashes.* Construction and Building Materials, 2016. **128**: p. 248-255.
249. Amran, M., S. Debbarma, and T. Ozbakkaloglu, *Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties.* Construction and Building Materials, 2021. **270**: p. 121857-121857.
250. Langan, B.W., K. Weng, and M.A. Ward, *Effect of silica fume and fly ash on heat of hydration of Portland cement.* Cement and Concrete Research, 2002. **32**(7): p. 1045-1051.
251. Singh, L., et al., *Quantification and characterization of CSH in silica nanoparticles incorporated cementitious system.* Cement and Concrete Composites, 2017. **79**: p. 106-116.
252. Ren, J., Y. Lai, and J. Gao, *Exploring the influence of SiO2 and TiO2 nanoparticles on the mechanical properties of concrete.* Construction and Building Materials, 2018. **175**: p. 277-285.
253. Samadi, M., et al., *Influence of glass silica waste nano powder on the mechanical and microstructure properties of alkali-activated mortars.* Nanomaterials, 2020. **10**(2): p. 324.
254. Huseien, G.F., *Durability Performance of Ceramic Waste–Based Alkali-Activated Mortars*, in *Recycled Ceramics in Sustainable Concrete*. 2020, CRC Press. p. 159-186.
255. Mohajerani, A., et al., *Nanoparticles in Construction Materials and Other Applications, and Implications of Nanoparticle Use.* Materials (Basel), 2019. **12**(19).
256. Abbas, Z.K., H.A. Mahdi, and B.A. Tayeh, *Producing Sustainable Concrete using Nano Recycled Glass.* The Open Civil Engineering Journal, 2021. **15**(1).
257. Manikandan, P. and V. Vasugi, *A critical review of waste glass powder as an aluminosilicate source material for sustainable geopolymer concrete production.* Silicon, 2021. **13**(10): p. 3649-3663.

258. Lin, K.-L., et al., *Effect of composition on characteristics of thin film transistor liquid crystal display (TFT-LCD) waste glass-metakaolin-based geopolymers.* Construction and Building Materials, 2012. **36**: p. 501-507.
259. Rashad, A.M., *Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement.* Construction and building materials, 2014. **72**: p. 340-357.
260. Shi, C. and K. Zheng, *A review on the use of waste glasses in the production of cement and concrete.* Resources, conservation and recycling, 2007. **52**(2): p. 234-247.
261. Jiang, Y., et al., *A critical review of waste glass powder–Multiple roles of utilization in cement-based materials and construction products.* Journal of environmental management, 2019. **242**: p. 440-449.
262. Idir, R., M. Cyr, and A. Tagnit-Hamou, *Pozzolanic properties of fine and coarse color-mixed glass cullet.* Cement and Concrete Composites, 2011. **33**(1): p. 19-29.
263. Pereira-de-Oliveira, L.A., J.P. Castro-Gomes, and P.M. Santos, *The potential pozzolanic activity of glass and red-clay ceramic waste as cement mortars components.* Construction and Building Materials, 2012. **31**: p. 197-203.
264. Mirzahosseini, M. and K.A. Riding, *Influence of different particle sizes on reactivity of finely ground glass as supplementary cementitious material (SCM).* Cement and Concrete Composites, 2015. **56**: p. 95-105.
265. Liu, G., M.V.A. Florea, and H.J.H. Brouwers, *Characterization and performance of high volume recycled waste glass and ground granulated blast furnace slag or fly ash blended mortars.* Journal of Cleaner Production, 2019. **235**: p. 461-472.
266. Du, H. and K.H. Tan, *Properties of high volume glass powder concrete.* Cement and Concrete Composites, 2017. **75**: p. 22-29.
267. Zhang, L. and Y. Yue, *Influence of waste glass powder usage on the properties of alkali-activated slag mortars based on response surface methodology.* Construction and Building Materials, 2018. **181**: p. 527-534.
268. Schwarz, N. and N. Neithalath, *Influence of a fine glass powder on cement hydration: Comparison to fly ash and modeling the degree of hydration.* Cement and Concrete Research, 2008. **38**(4): p. 429-436.

269. Lee, H., et al., *Performance evaluation of concrete incorporating glass powder and glass sludge wastes as supplementary cementing material.* Journal of Cleaner Production, 2018. **170**: p. 683-693.

270. Aliabdo, A.A., M. Abd Elmoaty, and A.Y. Aboshama, *Utilization of waste glass powder in the production of cement and concrete.* Construction and Building Materials, 2016. **124**: p. 866-877.

271. Siad, H., et al., *Use of recycled glass powder to improve the performance properties of high volume fly ash-engineered cementitious composites.* Construction and Building Materials, 2018. **163**: p. 53-62.

272. Jain, K.L., G. Sancheti, and L.K. Gupta, *Durability performance of waste granite and glass powder added concrete.* Construction and Building Materials, 2020. **252**: p. 119075.

273. Islam, G.M.S., M.H. Rahman, and N. Kazi, *Waste glass powder as partial replacement of cement for sustainable concrete practice.* International Journal of Sustainable Built Environment, 2017. **6**(1): p. 37-44.

274. Wu, M., B. Johannesson, and M. Geiker, *A review: Self-healing in cementitious materials and engineered cementitious composite as a self-healing material.* Construction and Building Materials, 2012. **28**(1): p. 571-583.

275. Osman, K.M., et al., *Role of different microorganisms on the mechanical characteristics, self-healing efficiency, and corrosion protection of concrete under different curing conditions.* Journal of Building Engineering, 2021. **41**: p. 102414.

276. Cabrera, M., A.P. Galvín, and F. Agrela, *Leaching issues in recycled aggregate concrete*, in *New Trends in Eco-efficient and Recycled Concrete*. 2019, Elsevier. p. 329-356.

277. Huseien, G.F., A.T. Saleh, and S.K. Ghoshal, *Effective Microorganism Solution and High Volume of Fly Ash Blended Sustainable Bio-Concrete.* Biomimetics (Basel), 2022. **7**(2).

278. Huseien, G.F., et al., *Compressive strength and microstructure properties of modified concrete incorporated effective microorganism and fly ash.* Materials Today: Proceedings, 2021. **46**: p. 2036-2044.

279. Wang, H. and Q. Li, *Prediction of elastic modulus and Poisson's ratio for unsaturated concrete.* International Journal of Solids and Structures, 2007. **44**(5): p. 1370-1379.

280. Rashad, A.M. and M. Ezzat, *A Preliminary study on the use of magnetic, Zamzam, and sea water as mixing water for alkali-activated slag pastes.* Construction and Building Materials, 2019. **207**: p. 672-678.
281. Huseien, G.F., et al., *Development of a sustainable concrete incorporated with effective microorganism and fly Ash: Characteristics and modeling studies.* Construction and Building Materials, 2021. **285**.
282. Jonkers, H.M., et al., *Application of bacteria as self-healing agent for the development of sustainable concrete.* Ecological Engineering, 2010. **36**(2): p. 230-235.
283. Krishnapriya, S., D.L. Venkatesh Babu, and P.A. G, *Isolation and identification of bacteria to improve the strength of concrete.* Microbiol Res, 2015. **174**: p. 48-55.
284. Ghosh, S., et al., *Microbial activity on the microstructure of bacteria modified mortar.* Cement and Concrete Composites, 2009. **31**(2): p. 93-98.
285. Zakaria, Z., S. Gairola, and N.M. Shariff, *Effective microorganisms (EM) technology for water quality restoration and potential for sustainable water resources and management.* 2010.
286. Kadapure, S.A., G.S. Kulkarni, and K. Prakash, *A laboratory investigation on the production of sustainable bacteria-blended fly ash concrete.* Arabian Journal for Science and Engineering, 2017. **42**(3): p. 1039-1048.
287. Ismail, N., et al. *The Effect of Effective Microorganism (EM) Inclusion to the Setting Time of Microbed Cement Paste*. in *MATEC Web of Conferences*. 2017. EDP Sciences.
288. Nathaniel, O., et al., *Biogenic approach for concrete durability and sustainability using effective microorganisms: A review.* Construction and Building Materials, 2020. **261**.
289. Kadapure, S.A., G.S. Kulkarni, and K. Prakash, *Study on properties of bacteria-embedded fly ash concrete.* Asian Journal of Civil Engineering, 2019. **20**(5): p. 627-636.
290. Mohammed, S., N. Rahim, and M. Roslan. *Effect of Effective Microorganisms (EM) on concrete performance*. in *IOP Conference Series: Earth and Environmental Science*. 2020. IOP Publishing.
291. Qin, R., et al., *Effect of shrinkage reducing admixture on new-to-old concrete interface.* Composites Part B: Engineering, 2019. **167**: p. 346-355.

292. Zuo, W., et al., *Effects of novel polymer-type shrinkage-reducing admixture on early age autogenous deformation of cement pastes.* Cement and Concrete Research, 2017. **100**: p. 413-422.

293. Zhou, M., et al., *Study on hydration characteristics of circulating fluidized bed combustion fly ash (CFBCA).* Construction and Building Materials, 2020. **251**: p. 118993.

294. EN, B., *8500-1: 2015. Concrete Complementary British Standard to BS EN 206-1-Part 1: Method of specifying and guidance for the specifier.* British Standards Institution, London, 2006.

295. BS, B., *8500–2: Concrete–Complementary British Standard to BS EN 206–1–Part 2: Specification for Constituent Materials and Concrete.* United Kingdom, 2006.

296. Standard, B., *8110: Part 1, Structural use of concrete–code of practice for design and construction.* British Standards Institute, London UK, 1985. **38**.

297. Standard, B., *118.(1983). Methods of Testing concrete, Method for determination of compressive strength of concrete cubes.* British Standards Institution, Londen, 1881.

298. 12390, B.E., *Testing hardened concrete, method of determination of compressive strength of concrete cubes*. 2000, British Standards Institution UK.

299. Schowalter, W. and G. Christensen, *Toward a rationalization of the slump test for fresh concrete: comparisons of calculations and experiments.* Journal of Rheology, 1998. **42**(4): p. 865-870.

300. Arowojolu, O., et al., *Feasibility study on concrete performance made by partial replacement of cement with nanoglass powder and fly ash.* International Journal of Civil Engineering, 2019. **17**(7): p. 1007-1014.

301. Hisseine, O.A. and A. Tagnit-Hamou, *Development of ecological strain-hardening cementitious composites incorporating high-volume ground-glass pozzolans.* Construction and Building Materials, 2020. **238**: p. 117740.

302. Sathyan, D. and K.B. Anand, *Influence of superplasticizer family on the durability characteristics of fly ash incorporated cement concrete.* Construction and Building materials, 2019. **204**: p. 864-874.

303. Cho, Y.K., S.H. Jung, and Y.C. Choi, *Effects of chemical composition of fly ash on compressive strength of fly ash cement mortar.* Construction and Building Materials, 2019. **204**: p. 255-264.
304. Lam, L., Y. Wong, and C.S. Poon, *Degree of hydration and gel/space ratio of high-volume fly ash/cement systems.* Cement and concrete research, 2000. **30**(5): p. 747-756.
305. Thomas, M., *Optimizing the use of fly ash in concrete*. Vol. 5420. 2007: Portland Cement Association Skokie, IL, USA.
306. Iqbal, D.M., L.S. Wong, and S.Y. Kong, *Bio-Cementation in Construction Materials: A Review.* Materials, 2021. **14**(9): p. 2175.
307. Reddy, S., et al., *Performance of standard grade bacterial (Bacillus subtilis) concrete.* Asian J Civ Eng (Build Housing), 2010. **11**: p. 43-55.
308. Chahal, N., R. Siddique, and A. Rajor, *Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete.* Construction and Building Materials, 2012. **28**(1): p. 351-356.
309. Siddique, R. and N.K. Chahal, *Effect of ureolytic bacteria on concrete properties.* Construction and building materials, 2011. **25**(10): p. 3791-3801.
310. Chatterjee, A., et al., *Bacterium-incorporated fly ash geopolymer: a high-performance, thermo-stable cement alternative for future construction material.* Clean Technologies and Environmental Policy, 2019. **21**(9): p. 1779-1789.
311. Abdulkareem, M., et al., *Evaluation of effects of multi-varied atmospheric curing conditions on compressive strength of bacterial (bacillus subtilis) cement mortar.* Construction and Building Materials, 2019. **218**: p. 1-7.
312. Belie, N., *Application of bacteria in concrete: a critical review.* RILEM Technical Letters, 2016. **1**: p. 56-61.
313. Achal, V., X. Pan, and N. Özyurt, *Improved strength and durability of fly ash-amended concrete by microbial calcite precipitation.* Ecological Engineering, 2011. **37**(4): p. 554-559.
314. Bundur, Z.B., M.J. Kirisits, and R.D. Ferron, *Biomineralized cement-based materials: Impact of inoculating vegetative bacterial cells on hydration and strength.* Cement and Concrete Research, 2015. **67**: p. 237-245.

315. Wang, J., et al., *Application of microorganisms in concrete: a promising sustainable strategy to improve concrete durability.* Applied microbiology and biotechnology, 2016. **100**(7): p. 2993-3007.
316. Huseien, G.F., et al., *Durability performance of modified concrete incorporating fly ash and effective microorganism.* Construction and Building Materials, 2021. **267**: p. 120947.
317. Halaweh, M.A., *Effect of alkalis and sulfate on Portland cement systems*. 2007: University of South Florida.
318. Li, H., M.-h. Zhang, and J.-p. Ou, *Abrasion resistance of concrete containing nano-particles for pavement.* Wear, 2006. **260**(11): p. 1262-1266.
319. Li, Y., B. Wu, and R. Wang, *Critical review and gap analysis on the use of high-volume fly ash as a substitute constituent in concrete.* Construction and Building Materials, 2022. **341**: p. 127889.
320. Ghosh, S., et al., *Microbial activity on the microstructure of bacteria modified mortar.* Cement and Concrete Composites, 2009. **31**(2): p. 93-98.
321. Abd Rahman, N.A. and A.R.M. Sam. *Properties of Normal Cement Concrete Containing Effective Microorganism*. in *The 11th International Civil Engineering Postgraduate Conference-The 1st Int. Symposıum On Expertise of Engineering Design*. 2016.
322. Elaqra, H. and R. Rustom, *Effect of using glass powder as cement replacement on rheological and mechanical properties of cement paste.* Construction and Building Materials, 2018. **179**: p. 326-335.
323. Kamali, M. and A. Ghahremaninezhad, *An investigation into the hydration and microstructure of cement pastes modified with glass powders.* Construction and Building Materials, 2016. **112**: p. 915-924.
324. Kayali, O. and M.S. Ahmed, *Assessment of high volume replacement fly ash concrete–Concept of performance index.* Construction and Building Materials, 2013. **39**: p. 71-76.
325. Yoon, S., et al., *Statistical evaluation of the mechanical properties of high-volume class F fly ash concretes.* Construction and Building Materials, 2014. **54**: p. 432-442.
326. Yoshitake, I., et al., *Thermal stress of high volume fly-ash (HVFA) concrete made with limestone aggregate.* Construction and Building Materials, 2014. **71**: p. 216-225.

327. Liu, Z., C.S. Chin, and J. Xia, *Improving recycled coarse aggregate (RCA) and recycled coarse aggregate concrete (RCAC) by biological denitrification phenomenon.* Construction and Building Materials, 2021. **301**: p. 124338.
328. Reddy, B.M.S. and D. Revathi, *An experimental study on effect of Bacillus sphaericus bacteria in crack filling and strength enhancement of concrete.* Materials Today: Proceedings, 2019. **19**: p. 803-809.
329. Venkovic, N., L. Sorelli, and F. Martirena, *Nanoindentation study of calcium silicate hydrates in concrete produced with effective microorganisms-based bioplasticizer.* Cement and Concrete Composites, 2014. **49**: p. 127-139.
330. Rodríguez, C.R., et al., *Chemo-physico-mechanical properties of the interface zone between bacterial PLA self-healing capsules and cement paste.* Cement and Concrete Research, 2020. **138**.
331. Porter, H., N.K. Dhami, and A. Mukherjee, *Synergistic chemical and microbial cementation for stabilization of aggregates.* Cement and Concrete Composites, 2017. **83**: p. 160-170.
332. Biswas, M., et al., *Bioremediase a unique protein from a novel bacterium BKH1, ushering a new hope in concrete technology.* Enzyme and Microbial Technology, 2010. **46**(7): p. 581-587.
333. Liu, C., et al., *Experimental on repair performance and complete stress-strain curve of self-healing recycled concrete under uniaxial loading.* Construction and Building Materials, 2021. **285**.
334. He, Z.-h., et al., *Creep behavior of concrete containing glass powder.* Composites Part B: Engineering, 2019. **166**: p. 13-20.
335. Jiang, Y., et al., *A critical review of waste glass powder - Multiple roles of utilization in cement-based materials and construction products.* J Environ Manage, 2019. **242**: p. 440-449.
336. Bostanci, L., *Effect of waste glass powder addition on properties of alkali-activated silica fume mortars.* Journal of Building Engineering, 2020. **29**.
337. 318, A.C. *Building Code Requirements for Structural Concrete (ACI 318-14): An ACI Standard; Commentary on Building Code Requirements for Structural Concrete (ACI 318R-14).* 2014. American Concrete Institute.
338. Sikora, P., et al., *Evaluating the effects of nanosilica on the material properties of lightweight and ultra-lightweight concrete using image-based approaches.* Construction and Building Materials, 2020. **264**: p. 120241.

339. Patel, D., et al., *Effective utilization of waste glass powder as the substitution of cement in making paste and mortar.* Construction and Building Materials, 2019. **199**: p. 406-415.

340. Parghi, A. and M.S. Alam, *Physical and mechanical properties of cementitious composites containing recycled glass powder (RGP) and styrene butadiene rubber (SBR).* Construction and Building Materials, 2016. **104**: p. 34-43.

341. Richardson, I., *Tobermorite/jennite-and tobermorite/calcium hydroxide-based models for the structure of CSH: applicability to hardened pastes of tricalcium silicate, β-dicalcium silicate, Portland cement, and blends of Portland cement with blast-furnace slag, metakaolin, or silica fume.* Cement and concrete research, 2004. **34**(9): p. 1733-1777.

342. Deb, P.S., P.K. Sarker, and S. Barbhuiya, *Effects of nano-silica on the strength development of geopolymer cured at room temperature.* Construction and Building Materials, 2015. **101**: p. 675-683.

343. Sargam, Y. and K. Wang, *Quantifying dispersion of nanosilica in hardened cement matrix using a novel SEM-EDS and image analysis-based methodology.* Cement and Concrete Research, 2021. **147**.

344. Hou, D., et al., *Insights on the molecular structure evolution for tricalcium silicate and slag composite: From 29Si and 27Al NMR to molecular dynamics.* Composites Part B: Engineering, 2020. **202**: p. 108401.

345. Zheng, Q., et al., *Aluminum-induced interfacial strengthening in calcium silicate hydrates: structure, bonding, and mechanical properties.* ACS Sustainable Chemistry & Engineering, 2020. **8**(7): p. 2622-2631.

PUBLICATION

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AM Onaizi, NHAS Lim, GF Huseien, M Amran, CK Ma (2021). Effect of the addition of nano glass powder on the compressive strength of high volume fly ash modified concrete. Materials Today: Proceedings, 48, 1789-1795. https://doi.org/10.1016/j.matpr.2021.08.347