An Overview: Supplementary Cementitious Materials

Pooja Jha, A. K. Sachan, and R. P. Singh

Abstract In the present scenario, there is a large production of agriculture wastes (AWs) and industrial waste (IW) have produced severe environmental problems related to their safe disposal. This review paper deals with the feasible usage of different types of debris like AW and IW in the production of mortar and concrete. These are used as supplementary cementitious material (SCM) to enhance the workability (WA), strength along with the durability properties of the concrete. It reviews on the evaluation of various physical properties of these wastes (AW and IW) includes fly ash (FA), ground granulated blast furnace slag (GGBFS), and silica fume (SF) and usefulness in the concrete production. It is used as SCM and can be advantageous in the strength and durability properties of concrete. It describes the influence of the addition of SCMs on the fresh properties (FP) and hardened properties (HP) of a concrete mortar without affecting the quality of concrete. Due to the similar properties of cement, these wastes may be used as a cement substitute and cement additive in the concrete industry. It also describes the utilization of the new emerging wastes like ground waste expanded perlite (WEP), and it is used as pozzolanic material (PM) and valuable SCMs. Due to its substantial activity, WEP can be used as a cement additive as well as a cement substitute.

Keyword Wastes · Concrete · High-performance concrete · Pozzolanic material · Waste expanded perlite

---

P. Jha (✉) · A. K. Sachan · R. P. Singh
Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad 211004, India
e-mail: rce1607@mnnit.ac.in

A. K. Sachan
e-mail: sachan@mnnit.ac.in

R. P. Singh
e-mail: rps@mnnit.ac.in

A. K. Gupta et al. (eds.), *Advances in Construction Materials and Sustainable Environment*, Lecture Notes in Civil Engineering 196,
https://doi.org/10.1007/978-981-16-6557-8_5

1 Introduction

Nowadays, the most vital building material used in the construction industry is concrete. It has reported that portland cement (PC) utilization improved drastically over a period little more than a century (1880–1990). Therefore, the process of cement manufacturing is the main reason for CO_2 emission and worldwide, it is the third-largest CO_2 producer. Cement industry alone generated seven percent of all CO_2 in the world [1]. There are drastic increases in the emission of CO_2 from cement production has been seen [2, 3]. To overcome these problems, cement can be replaced by producing a new emerging material that is the SCMs. These are the PM, which can be classified as natural pozzolana (NP) as well as artificial pozzolana (AP). The NP can be generally found in volcanic tuffs, and the AP can be obtained from FA and metallurgical slags, etc. [4, 5]. Many researchers [6–8] have observed that these SCMs are by-products materials that enhance concrete construction properties and also protect environmental resources (included sustainability of concrete). Naik and Singh [9] have studied that these SCMs may decrease the early strength (ES) of concrete, mainly if the cement replacement rate (CRR) is more. Still, at optimum replacement percentage, it is producing valuable, strong, and durable concrete. SCM is by-product of silicon (Si) and aluminum (Al). Al and Si contents have various benefits such as reduced permeability, reduced segregation, resistance against the freeze, and resistance against sulfate attack of concrete. Not only this, but it has also improved the compressive strength (CS) as well as durability (DB) of concrete.

In this paper, several AW and IW have been described and introduced. In this paper, the introduction and explanation of the AW and IW materials as SCMs for concrete. It also describes its influence of the addition of SCMs on the properties of concrete and mortar. It has also been described as expanded perlite (EP), which is used as the new effective SCM. It is used mostly in horticulture and agriculture as well as in the building materials technology (acoustic, lightweight composites, fire insulation, and thermal insulation). Various techniques like abrasives and filtration use, specially prepared expanded perlite.

2 Waste Material as SCM

The classification and specifications of different SCMs like FA and GGBFS are given below in Tables 1, 2, and 3.

The various SCMs as per the standards along with the uses are given in Table 3.

The uses of SCMs in concrete are beneficial in many ways. Their purposes enhance and accelerate the strength of concrete, improve the resistance against sulfate attack, resistance against chloride ions, and making concrete easier to pump. SCMs also play a useful role in reducing the water permeability and other fluids, deleterious expansion, and risk of delayed ettringite formation.

Table 1 Classification and specifications for FA as per [10]

Specifications	Types
Volcanic ashes or pumicites and tuffs	Class N (raw pozzolana)
Diatomaceous earth	
Opaline cherts and shales	
Calcined clays	
Pozzolanic properties	Class F
Pozzolanic and cementitious properties	Class C

Table 2 Classification and specifications for GGBFS as per [11]

Specifications	Types
Low activity index (LAI)	Grade 80
Moderate activity index (MAI)	Grade 100
High activity index (HAI)	Grade 120

Table 3 Classification, uses, and specifications of various SCMs

Standards	SCMs	Uses
Standard specification for coal FA and raw or calcined natural pozzolana for use as a mineral admixture in PC concrete [10]	Coal FA and raw or calcined natural pozzolan	Concrete
Specification for GGBFS for use in concrete and mortar [11]	GGBFS	Concrete and mortar
Specification for SF for use in concrete and mortar [12]	SF	Cementitious mixture

2.1 Different Types of SCMs

FA: FA is a siliceous or alumina siliceous material which can be used as cement replacement material (CRM) due to similar properties of cement. It improves workability, strength in long-term basis, resistance against sulfate attack, and DB in concrete. FA is formed from the coal burning in electric power generation plants, and it has high pozzolanic activity [13]. Due to its chemical properties and mineral constituents, the color of FA may change from tan to dark gray. There are various predominant areas of FA applications. They are the production of concrete [14], cement clinkers [15], waste solidification [16], more geopolymer concrete in the fresh state [17], and road basement material [18]. Cement is replaced by FA, which is used as a CRM, makes the conventional and high-performance concrete, which is used as an SCM in the construction industry. Similarly, the environmental advantages of waste disposal and CO_2 sequestration [19, 20]. In the fresh properties of concrete, it means at early ages, FA improves workability, thermal cracking reduces and heat of hydration also lowers in concrete and in the hardened state such that at the later periods, it enhances the various properties like durability as well mechanical properties of concrete [21]. There are many limitations of FA, and one of the flaws reported by Vargas and Halog [22] is that the full utilization of FA is not achieved, and it is partially replaced by the cement. Lam et al. [23] have described the various properties of FA concrete-like mechanical, fracture, and durable properties, and its effect of different type of FA on multiple other properties like freeze–thaw resistance has been reported by Uysal and Akyuncu [24]. The maximum percentage of FA used is restricted to 35% in the manufacturing of portland pozzolana cement as per the code IS-1489, 2000. From the literature review, it has seen that when FA beyond 35% replaces cement, the strength characteristics are not increases and show a decreasing rate after attaining the optimum replacement value. In most cases, like FA cement needs improvement to enhance the strength in the mix by making more products of hydration. It is possible to attain more significant than 50% replacement of FA by the proper engineering procedure.

GGBFS: GGBFS is made of the material used to make iron and produced by the blast furnace. At a temperature of approximately 1600 °C, different products like molten slag (MS) and molten iron (MI) have formed by the combination of coke, limestone, and iron ore in the furnace. Malhotra et al. [6] have reported that the leading country in the world which produced GGBFS was Germany. For public purposes, it has also been used in North America. Molten slag is made mostly of silicon dioxide ranges from 30 to 40% and calcium dioxide ranges from 40%. By using high-pressure water jets, silicates, and alumina, which are the essential components in molten slag has cooled down [25]. Therefore, granular glassy material is formed during rapid cooling, which has latent hydraulic properties at temperature ranges from 900–800 °C results in noncrystalline slag. 35–65% replacement level of GGBFS may prove to be advantageous in concrete, which also helps in reducing the carbon dioxide production. There are three strength grades of GGBFS (Grade 80, 100, and 120) as per ASTM C 98911.

SF: SF is manufactured from silicon metal, ferrosilicon alloy, which is collected from the oxidized vapor on the top of the electric arc furnaces, and it is being used as supplementary cementing material for concrete elements. SF also known as condensed silica fumes (CSF), microsilica, silica dust, volatilized silica, and micropores (trademark name). Most of the silica fume particles are ultra-fine particles and spherical. Due to its high fineness and glass content, SF shows a high pozzolanic reactivity, which is very constructive when used in concrete. The SF replacement level is 5–10% when replacing the cement with SF [26]. Mechanical properties of concrete are affected substantially as consequences of strengthening the interfacial zone. Amoudi et al. [27] have studied that SF has a vital influence on the aggregate-cement interface (ACI). Due to high pozzolanic and extreme fineness, its addition produces less permeability concrete. Nguyen et al. [28] have documented that the effects of rice husk ash (RHA) and SF in both binary systems as well as ternary system on the property of cement pastes, and the CS of concrete was studied. The various physical properties (PP) and

Table 4 Typical physical properties (PP) of various SCMs

PP	FA (Range) [29]	GGBFS (Range) [30]	SF (Range) [29]
Particles size (PS)	<1 μm to >100 μm	<45 μm	<1 μm
Diameter of the particles (D)	<20 μm in size	–	
Surface area (SA)	300–500 m^2/kg (min surface are 200 m^2/kg Max surface area 700 m^2/kg)	400–600 m^2/kg	13.000–30.000 m^2/kg
Density (p)	540–860 m^2/kg	–	481–720 kg/m^3
Max bulk density under close-packed storage (BD)	1120–1500 kg/m^3	–	131–430 kg/m^3
Specific gravity (SG)	1.9–2.9	2.61	2.22

Table 5 Typical chemical properties (CP) of various SCMs

Chemical composition	FA % by mass [31]	GGBFS % by mass [32]	SF % by mass [33]
SiO_2	27.88–59.40	35	95.3
CaO	0.37–27.68	40	0.3
Al_2O_3	5.23–33.99	13	0.6
Fe_2O_3	1.21–29.63	–	0.3
MgO	0.42–8.79	8	0.4
Na_2O	0.20–6.90	–	0.3
SO_3	0.04–4.71	–	–
K_2O	0.64–6.68	–	0.8
TiO_2	0.24–1.73	–	–
LOI	0.21–28.37	–	–

chemical properties (CP) of various SCMs such as FA, GGBFS, and SF as shown in Tables 4 and 5.

2.2 *The Influence of SCMs on the FP of Concrete*

The slump test (ST) can be performed to evaluate the FP of the concrete. Fine SCMs, mainly metakaolin and SF, are used to reduce the slump and expand the water consumption [34, 35]. However, not all SCMs increase in water consumption. For example, FA as well as GGBFS reduce the water demand and also enhancing the properties of fresh concrete at the same time [35]. Therefore, Gesoglu et al. [36] have found that that the higher replacement levels are necessary if better results are desired, which was manifest in the study carried out by. They could also add the mineral admixtures and increase the filling and passing ability of self-compacting concrete by [37]. They had also documented that there was higher in the water reduction effect when FA was used as an SCM with a 40% replacement level. Similar outcomes can also be seen by integrating FA and superplasticizers in HPC. The same approach has seen because the consequences of their study showed that the inclusion of these two materials enhances the WA as well as the concrete performance [38].

2.3 The Influence of SCMs on the HP and DP of Concrete

SCMs lower the porosity of the concrete. Filling the available voids in the cement to enhance CS and DB by introducing SCMs in it. Due to hydration, the inclusion of FA to concrete cannot only minimize the dense packing and water content (WC) but also increases the hydration and pozzolanic reactions, which consequences to decelerate the permeability of concrete. The calcium hydroxide $Ca(OH)_2$ can develop voids permeable in nature in the hardened concrete during the hydration process. By adding calcium hydroxide during the pozzolanic reaction, the leaching of calcium hydroxide can be minimized. Voids can be choked by calcium silicate hydrate gel in the chemical reaction and added to the density of the concrete, which in turn lowers the permeability. SCMs such as SF, RHA, and metakaolin play an essential role in early age as well as later-age strength improvement in concrete [35, 39]. On the other hands of FA and GGBFS, this strength improvement does not occur at an early age [35]. The proportions of slag, SF, and FA had increased to attain better CS [40]; these proportions studied as 17% for slag, 15% for SF, and 10% for FA.

During the winter season, the CS of concrete produced showed an increase of approximately 5% in emissions of CO_2 compared with concrete produced in the season concluded by [41]. Besides, they showed that the amount of CO_2 emitted for concrete containing SCM was lowered by as much as 47% compared with concrete without SCM. The reason for these consequences is due to the cement replacement and admixtures that have a remarkable amount of carbon dioxide with materials such as FA or GGBFS, which have a lower amount of CO_2. Due to the combined effects of the multi binder on high-performance concrete, the CS significantly reduced. A considerable part of SF and FA reported to be the essential factor affecting properties included the drying shrinkage. Specimens of silica fume and metakaolin have more CS. Borhan et al. [42] have studied the porosity, CS, permeability, and resistance to chemical agents of multi blended mortar (MB mortar) containing FA and SF. The outcomes show that strength was 20% lower for the MB concrete at an early age, while at the final-age, strength of both the control mortar and the MB concrete was approximately the same. Therefore, the MB concrete outperformed the control mortar in terms of low permeability. SCMs improve against the sulfate resistance due to good pozzolanic activity that enhanced the microstructure and prevent the formation of ettringite which is major factor of sulfate attack [43].

Table 6 Properties of WEP [44]

WEP	Range
PS	<100 μm
BD	50–150 kg/m^3

Table 7 Variation of CS by partially replacing the cement with WEP

% Replacement of WEP	0	10	20	30	40	References
CS (N/mm^2) at 28 days	43.3	40	39	40	–	[45]
CS (N/mm^2) at 28 days	28.8	–	17.3	–	10.9	[46]

2.4 Applications of WEP as New Constructive SCM

There was worldwide usage of the expanded perlite (EP) as a cementitious material. EP used as valuable lightweight building materials used in the agriculture industry. Fined grained WEP is being formed during both productions as well as the processing of EP. By the incorporation of ground WEP, consequences of strength tests showed that strength roughly to 50%. Ground WEP can be used as a cement additive as well as a cement substitute due to its high activity. Some properties of WEP are shown in Table 6, and variation of CS. by partially replacing the cement with WEP shown in Table 7.

The possibility of usage of raw perlite rock as a cement additive [47]. Rezazanipour et al. [48] showed to evaluate the application of WEP as SCM was conducted. He also studied the use of WEP as SCM. Many researchers worked on the various SCMs used in cement as well as the concrete industry; there are calcined clays, GGBFS [15], limestone [49], FA [22], and natural zeolites [50]. In an industry like binding materials science, SCMs are one of the most predominant topics [16]. The various content of portland clinker lowers by the addition of SCM in cement, and it also reduces the total amount of CO_2 liberates [51]. In industries like autoclaved aerated concrete manufacturing, EP can be used as quartz sand replacement. Thermal conductivity lowers by 15% without an essential reduction of strength by replacement of 10% sand [51]. The cement replaced by calcined raw perlite rock, which increases the properties of concrete in the HS includes the DB properties [51].

3 Conclusions

In the concrete mixture, the SCM will be a vital interest and a practical solution for sustainable construction and also construct greening in respect to the environment. The following conclusions are derived below:

1. The SCMs have been proven to crucial materials to enhance the strength and performance of concrete. These materials have a positive influence on the

concrete performance included FP, HP (CS and tensile strength (TS)), and drying shrinkage.

2. Various issues (environmental, technical, and economic) caused by cement production has neutralized or minimized by the introduction of SCMs in cement or concrete. Most of these SCMs are by-products, and their addition serves as a crucial means to save environmental resources, which may result in more viable constructions in future.
3. Usage of cement has minimized through the SCMs by the introduction of SCMs are added to concrete, which may lead to the environmental benefits of lower emission of CO_2.
4. There is growth in the manufacturing of FA to lower the effect on the environment and to revise the possibility in the sector of construction; there is a worldwide demand to understand the various advantage of FA usage in the concrete industry. While new procedures and technique are settling to engineer, the concrete with vast volumes of FA to create superior outcomes, due to the various types of problems like increased shrinkage, high carbonation, and slow development of strength, utilization of vast volumes of FA remain incomplete. Researchers focus on the concept of the green economy, which is significant to society as well as the environment. Therefore, the main principle binder used in concrete is portland cement (energy-intensive). It is also responsible for significant emissions of CO_2 gas called greenhouse gas, and the manufacturing of cement remarkably leads to global warming, which leads to the change in the climate. Hence, the improvement of existing knowledge and examination of further convenient IW as well as AW to be used as SCM in the mixture of concrete.
5. Cement mortar improvement along with ground WEP enables obtaining strength upgrade up to over fifty percent. The modification of the strength development rate mainly depends on the WEP content. WEP can be utilized as an additive and substitute for portland cement. The inclusion of WEP consequences is a higher strength development all over the hydration time, while replacement of cement at 28 days leads to a less reduction in early strength.

Acknowledgements The authors are grateful to Director MNNIT Allahabad for providing the necessary help and support required. One of the authors, Miss Pooja, a research scholar, is also appreciative to MHRD New Delhi, India, for providing financial assistance for research work.

Conflict of Interest: There is no conflict of interest.

References

1. Malhotra, V. M. (2002). Introduction: sustainable development and concrete technology. *Concrete International, 24*(7).

2. Taylor, M., Tam, C., & Gielen, D. (2006). Energy efficiency and CO2 emissions from the global cement industry. *Korea, 50*(2.2), 61–67.
3. Muga, H., Betz, K., Walker, J., Pranger, C., & Vidor, A. (2005). *Development of appropriate and sustainable construction materials*. Michigan Technological University, Michigan, USA.
4. Mehta, P. K. (1989) Pozzolanic and cementitious by-products in concrete—Another look. In: V. M. Malhotra (Ed.) *Proceedings 3rd International Conference on the Use of Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, ACI SP-114, Trondheim* (pp. 1–43).
5. Malhotra, V. M. (1987). *Supplementary Cementing Materials for Concrete*. Centre for Mineral and Energy Technology, Ottawa, Canada, p. 428.
6. Malhotra, V. M. (1996). *Pozzolanic and Cementitious Materials*. Gordon and Breach Publishers, Amsterdam, p. 208.
7. Aitcin, P. C. (1998). *High Performance Concrete*. Taylor and Francis, USA, ISBN-13: 9780419192701, p. 624.
8. Mehta, P. K., & Monteiro, P. J. M. (2006). *Concrete-Microstructure Properties and Materials* (3rd ed., p. 659). Mc Graw-Hill.
9. Naik, T. R., & Singh, S. S. (1998). Fly ash generation and utilization-an overview. In A. K. Suri & A. B. Harapanahalli (Eds.), *Recent Trends in Fly Ash Utilization* (pp. 1–25). SOFEM Publisher.
10. ASTM C 618-94. (1994). *Standard specification for coal fly ash and raw or calcined natural pozzolana for use as a mineral admixture in Portland cement concrete*. http://www.astm.org/Standards/C618.htm
11. ASTM C 989-93. (1993). *Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*. http://www.astm.org/Standards/C989.htm
12. ASTM C 1240-93. (1993). *Specification for Silica Fume for Use in Concrete and Mortars*. http://www.astm.org/Standards/C1240.htm
13. Haque, M. N., & Kayali, O. (1998). Properties of high-strength concrete using a fine fly ash. *Cement Concrete Research, 28*, 1445–1452.
14. Sivasundaram, V., Carette, G. G., & Malhotra, V. M. (1990). Long-term strength development of high-volume fly ash concrete. *Cement and Concrete Composites, 12*(4), 263–270.
15. Tironi, A., Trezza, M. A., Scian, N., & Irassar, E. F. (2013). Assessment of pozzolanic activity of different calcined clays. *Cement and Concrete Composites, 37*, 319–327.
16. Puertas, F., Varga, C., del Mar Alonso, M., Aranzazu Diaz-Batista, M., & Lizarraga, S. (2015). New technology for alternative pozzolanic additions for Portland cement from abandoned landfills Cement Wapno Beton, 2/2015, pp. 88–105.
17. Embong, R., Kusbiantoro, A., Shafiq, N., & Nuruddin, M. F. (2016). Strength and microstructural properties of fly ash based geopolymer concrete containing high-calcium and water-absorptive aggregate. *Journal of Cleaner Production, 112*, 816–822.
18. Sobolev, K., Vivian, I. F., Saha, R., Wasiuddin, N. M., & Saltibus, N. E. (2014). The effect of fly ash on the rheological properties of bituminous materials. *Fuel, 116*, 471–477.
19. Ukwattage, N., Ranjith, P., Yellishetty, M., Bui, H., & Xu, T. (2015). A laboratory-scale study of the aqueous mineral carbonation of coal fly ash for CO2 sequestration. *Journal of Cleaner Production, 103*, 665–674.
20. Dananjayan, R. R. T., Kandasamy, P., & Andimuthu, R. (2016). Direct mineral carbonation of coal fly ash for CO2 sequestration. *Journal of Cleaner Production, 112*, 4173–4182.
21. Aahmaran, M., & Li, V. C. (2009). Durability properties of micro-cracked ECC containing high volumes fly ash. *Cement and Concrete Research, 39*(11), 1033–1043.
22. Vargas, J., & Halog, A. (2015). Effective carbon emission reductions from using upgraded fly ash in the cement industry. *Journal of Cleaner Production, 103*, 948–995.
23. Lam, L., Wong, Y. L., & Poon, C. S. (2000). Degree of hydration and gel/space ratio of high-volume fly ash/cement systems. *Cement and Concrete Research, 30*, 747–756.
24. Uysal, M., & Akyuncu, V. (2012). Durability performance of concrete incorporating Class F and Class C fly ashes. *Construction and Building Materials, 34*, 170–178.
25. Higgins, D. (2007). Briefing: GGBS and sustainability. *Proceedings of the Institution of Civil Engineers Construction Materials, 160*, 99–101.

26. Kosmatka, S. H., Kerkhoff, B., & William, C. (2003). *Design and Control of Concrete Mixtures* (14th ed.). Portland Cement Association.
27. Al-Amoudi, O. S. B., Al-Kutti, W. A., Ahmad, S., & Maslehuddin, M. (2009). Correlation between compressive strength and certain durability indices of plain and blended cement concretes. *Cement and Concrete Composites, 31*(9), 672–676.
28. Nguyen, V. T. (2011). *Rice husk ash as a mineral admixture for ultra-high performance concrete.*
29. Terence, C. H. (2005). *Silica Fume User's Manual*, *Lovettsville, VA.*
30. Shumuye, E. D., & Jun, Z. (2018). A Review on Ground Granulated Blast Slag (GGBS) in Concrete. In: *Proceedings of the Eighth International Conference on Advances in Civil and Structural Engineering, CSE.*
31. Feng, X., & Clark, B. (2011). Evaluation of the physical and chemical properties of fly ash products for use in Portland cement concrete. In: *2011 World of Coal Ash Conference, Denver, CO, USA* (Vol. 9).
32. Suresh, D., & Nagaraju, K. (2015). Ground granulated blast slag (GGBS) in concrete–a review. *IOSR journal of mechanical and civil engineering, 12*(4), 76–82.
33. Nochaiya, T., Wongkeo, W., & Chaipanich, A. (2010). Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete. *Fuel, 89*(3), 768–774.
34. Neville, A. M. (2005). *Properties of Concrete*, 4th Edn. Pearson Education Ltd., Essex, England.
35. Safiuddin, M., & Zain, M. F. M. (2006). Supplementary cementing materials for high-performance concrete. *BRAC University Journal, 3*(2), 47–57.
36. Gesoglu, M., Guneyisi, E., & Ozbay, E. (2009). Properties of self-compacting concrete made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. *Construction and Building Materials, 23*, 1847–1854.
37. Wu, Z., & Naik, T. R. (2002). Properties of concrete produced from multicomponent blended cement. *Cement and Concrete Research, 32*, 1937–1942.
38. Yin, J., Zhou, S., Xie, Y., Chen, Y., & Yan, Q. (2002). Investigation on compounding and application of C80–C100 high-performance concrete. *Cement Concrete Research, 32*, 173–177.
39. Malhotra, V. M. (1993). Fly ash, slag, silica fume, and rice husk ash in concrete: A review. *Concrete International, 15*(4), 23–28.
40. Penga, Y., Hu, S., & Ding, Q. (2009). Dense packing properties of mineral admixtures in the cementitious material. *Particuology, 7*, 399–402.
41. Park, J., Tae, S., & Kim, T. (2012). Life cycle CO_2 assessment of concrete by compressive strength on the construction site in Korea. *Renewable Sustainable Energy Review, 16*, 2940–2946.
42. Borhan, M. N., Ismail, A., & Rahmat, R. A. (2010). Evaluation of palm oil fuel ash (POFA) on asphalt mixtures. *Australian Journal of Basic and Applied Sciences, 4*(10), 5456–5463.
43. Saha, A. K., & Sarker, P. K. (2020). Effect of sulphate exposure on mortar consisting of ferronickel slag aggregate and supplementary cementitious materials. *Journal of Building Engineering, 28*, 101012.
44. Kotwica, L., Pichor, W., Kapeluszna, E., & Rozycka, A. (2017). Utilization of waste expanded perlite as new effective supplementary cementitious material. *Journal of Cleaner Production, 140*, 1344–1352.
45. Ramezanianpour, A. A., Karein, S. M. M., Vosoughi, P., Pilvar, A., Isapour, S., & Moodi, F. (2014). Effects of calcined perlite powder as a SCM on the strength and permeability of concrete. *Construction and Building Materials, 66*, 222–228.
46. Sengul, O., Azizi, S., Karaosmanoglu, F., & Tasdemir, M. A. (2011). Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete. *Energy and Buildings, 43*(2–3), 671–676.
47. Erdem, T. K., Meral, C., Tokyay, M., & Erdogan, T. Y. (2007).Use of perlite as a pozzolanic addition in producing blended cement. *Cement and Concrete Composites, 29*, 13–21.
48. Ramezanianpour, A. A., Mahmoud Motahari Karein, S., Vosoughi, P., Pilvar, A., Isapour, S., Faramarz Moodi Beddar, M., Meddah, A., Boubakria, M., & Haddad, N. (2014). A study of the effects of partial replacement of clinker by limestone in the cement manufacture. *Cement Wapno Beton*, 3/2104, 185–193.

49. Markiv, T., Sobolev, K., Franus, M., & Franus, W. (2016). Mechanical and durability properties of concretes incorporating natural zeolite. *Archives of Civil and Mechanical Engineering, 16*, 554–562.
50. Juenger, M. C. G., & Siddique, R. (2015). Recent advances in understanding the role of supplementary cementitious materials in concrete. *Cement and Concrete Research, 78*, 71–80.
51. Rozycka, A., & Pichor, W. (2016). Effect of perlite waste addition on the properties of autoclaved aerated concrete. *Construction and Building Materials, 120*, 65–71.