



Review article

Effects of different supplementary cementitious materials on durability and mechanical properties of cement composite – Comprehensive review

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ABSTRACT

Ordinary Portland cement is the highest produced cement type in the world, however its production is high energy consumption means expensive, huge natural resource consumptive, and creating high environmental pollution. Hence many researchers studied to reduce the effect of ordinary Portland cement by substituting artificial and natural supplementary cementitious materials (SCMs) commonly in a concrete/mortar mixture. However, the comprehensive effect of different SCMs on various properties of cement composite materials are not well known. So the present study sought to review the effect of different natural and artificial SCMs on the durability and mechanical properties of cement composites, especially due to their doses, types, chemical composition, and physical properties. Hence the review shows that many SCMs used by literatures from different places satisfy ASTM replacement standard based on their chemical compositions. Also, the review indicated as adding 5–20% of different SCMs positively affect mechanical properties, durability, and microstructures of the cement composite materials, specifically as most researchers found isolately adding of 15% SCMs such as bentonite, kaolin, and biomass, 20% addition of volcanic ash and 10% employment of fly ash, silica fume, and zeolite to the cement composites achieves the most optimum compressive and split tensile strength. These observations reveal that most natural pozzolana can more replace cement to give optimum strength, hence can more reduce energy consumption, production cost, and environmental pollution comes due to cement production. Furthermore, most researchers found employing different SCMs generally improves durability, however there is a limited study on the effect of silica fume on water absorption and acidic attack resistance of cementitious materials. Therefore, it is recommended that future research should also focus more to know the effect of silica fume on the durability of cement composites.

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1. Introduction

Cement is the most fabricated product on Earth by mass and is the second most highly used substance in the world after water [1]. Hence the chemical compositions of cement clinker have to be controlled throughout the process of manufacturing good quality cement, which is mostly affected by the ingredient contents of the cement raw materials [2]. However, manufacturing cement widely contributes to environmental pollution [3,4]. That is because, it is a major consumer of natural resources and the process of cement production requires high temperatures, a large amount of energy consumption, and releasing CO₂ to the environment [5–9].

Especially the production of ordinary Portland cement is high energy consumption means very expensive, huge natural resource consumption, and creates environmental problems. But, due to the rapid growth of the population in the world, the demand for ordinary Portland cement increasing globally [10,11]. However, every ton of ordinary Portland cement production release about one ton of CO₂ into the environment [12]. Therefore, researchers have studied the efficiency, availability, and effectiveness of different supplement cementing materials that can be employed as cement replacement which can solve CO₂ emission comes due to cement production [12–19]. This is mainly because the calcination of SCMs especially clay requires much less calcination temperature than cement clinker [20]. However, there is a gap in which dose and types of SCMs either natural or artificial SCMs most beneficial for cement composites. So the aim of the present study is to review many literatures and indicates the most reliable doses and type of SCMs which can give optimum strength, better microstructure, and more increase durability of the cement composite, hence can highly reduce energy consumption and environmental pollution comes due to cement productions.

1.1. Significance of using SCM in cement replacement

Pozzolan is SCM commonly used as cement replacement in the concrete composite for a lot of significance in improving concrete performance, reducing cement consumption with significantly reducing CO₂ emission [10,16,21–48]. This is more supportive since cement is one of highest produced product and costly in the world due to it requires high energy for production, but adding of SCMs as a cement substitute is highly can reduce the amount of cement consumption required by the construction industry which means indirectly adding of SCMs encourages the economic sustainability of our countries.

Besides to these employing pozzolanic SCMs beneficial in the consumption of calcium hydrate in cement and producing secondary C–S–H. These improve the finer pore structure of the cement matrix compared to reference Ordinary Portland cement. Thus the concrete matrix becomes less permeable which can improve concrete durability [47,49–51]. Durability is mostly influenced by the physical and chemical properties of the hardened cement-based materials. Physically, the pore structure, including the pore volume, pore size distribution, tortuosity, and connectivity, which can determine the ease of external gases, liquids, and ions penetrating into the hardened cement matrix, that can deteriorate the concrete lifetime due to the ingress of external matter include carbonation, freeze/thaw damage, sulfate ions ingress [50,52].

In addition to improving durability, employing of SCMs beneficial for lowering cement production costs and environmental impact [18,52–57]. The same findings as SCMs are appealing for the improvement of durability and strength with highly reducing CO₂ emissions [38,56,58–70]. Also, supplementary cementing materials are an effective means for controlling expansion due to alkali-silica reactions. However, the decomposition of concrete arises when exposed to the sulfuric acid environment, which is the main issue that influences the life cycle, performance, and maintenance costs of concrete structures. Hence employing SCMs in a cement composite can enhance the sulfate resistance of concrete [12,49], improves resistance to chemical corrosion fracture toughness, and can resist low and high temperatures [71].

Additionally, SCMs from by-product or waste reflects promising performance as a partial replacement of cement composite materials which can reduce the consumption of natural resources [72] and reduces the production cost of cement factories with fulfilling demand-supply capacity [73]. Employment of SCMs in cement composite materials can be influenced by the amount of cement which is if the amount of cement is not sufficient, there is no reaction of calcium hydroxide by supplementary materials. And also the fineness of the supplementary cementitious material mostly affects the reactivity of SCM with free lime in cement [74]. That means the employment of SCMs in a cement lower amount of Portland clinker, which produces portlandite at hydration time and SCMs improves the consumption of portlandite in pozzolanic reaction [14,75].

Also, Ivashchyshyn et al. [76] studied the low-emission cement achieved by SCMs especially fly ash and zeolite decrease the bleeding because its surface area is higher than cement components with reducing energy consumption and improves strength to produce pozzolanic cement compared to ordinary Portland cement [77]. In addition, ductility is the potential of the structures to undergo much inelastic deformation beyond initial yield deformation that is without significant lessening of strength or stiffness. So the ductile structural membranes expected to withstand overloads, load reversals, impact, and structural moment may be caused by foundation settlement or volume change, hence employing SCMs in cement composite improves ductility [78,79].

Besides these, concrete is alkaline and chemical attack resistant, though can be affected by the acid attack in liquids having pH value below 6.5 and severe at below 5.5 and very severe below 4.5 pH value, that is because of easy dissolution and leaching of calcium hydroxide in hardened concrete, so SCMs is beneficial by its micro filling ability that can protect the entrance of acids from the reduction of concrete durability [50,80,81].

Furthermore, the incorporation of industrial by-products such as slag, fly ash, and silica fume positively affects concrete mixture [12,81]. Cement quality is typically assessed by the development of the compressive strength of mortar or concrete [2]. Also, long-term enhancement of compressive strength is evidence of hydraulic reaction and pozzolanicity of the SCMs [50,82]. Generally, SCMs either industrial by-products such as fly ash, silica fume, or natural Pozzolan mean like bentonite, kaolin, zeolite, and volcanic ashes are appealing for the technical, economical, and environmental benefit that is of great importance for sustainable building construction [9,

Table 1
Chemical composition of natural supplementary cementitious materials used in various research.

Bentonite													References
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Cl	LOI	SAF	
48.80	15.54	6.44	5.22	3.50	–	2.19	0.75	0.49	0.13	–	15.73	70.78	[88]
49.17	14.55	7.37	0.75	2.23	–	3.25	0.68	0.22	–	–	–	71.09	[89]
64.25	15.60	4.60	1.63	2.50	0.00	2.80	3.86	0.60	0.21	–	0.24	84.45	[90]
49.17	14.55	7.37	0.75	2.23	–	3.25	0.68	0.22	–	–	–	71.09	[89]
70.70	13.80	1.49	2.30	2.26	0.29	2.56	0.33	0.20	0.05	0.00	5.12	85.99	[91]
64.23	19.39	5.19	3.79	1.81	0.08	1.49	1.52	0.09	0.02	–	1.12	88.81	[92]
67.03	16.31	1.76	2.81	7.15	0.05	3.10	1.43	0.13	0.09	0.04	–	85.10	[93]
52.80	16.40	5.80	4.60	1.40	–	0.62	0.70	–	–	–	9.6	75.00	[94]
57.98	19.70	12.46	1.11	1.71	–	1.25	1.51	1.62	–	–	–	90.14	[95]
52.80	16.40	5.80	4.60	1.40	–	0.62	0.70	–	–	–	9.60	75.00	[96]
56.13	21.20	3.23	3.16	4.32	–	4.14	1.01	0.55	0.12	–	6.11	80.56	[97]
76.17	14.38	3.17	1.88	1.11	0.91	1.06	0.54	0.60	0.04	–	4.86	93.72	[98]
Kaolin													
71.78	14.04	5.50	0.46	–	0.00	–	4.58	0.33	0.21	–	0.72	91.32	[99]
56.30	37.42	1.20	0.02	0.46	0.08	0.07	3.51	0.69	–	–	–	94.92	[100]
66.52	21.96	0.85	0.20	0.37	–	0.83	0.00	–	–	–	–	89.33	[46]
74.2	17.60	0.85	3.32	0.25	0.43	0.00	0.34	–	–	–	–	92.65	[101]
62.18	21.67	6.05	3.01	3.41	–	1.03	1.85	1.03	–	–	0.50	89.90	[102]
55.10	34.10	5.40	0.28	0.25	0.01	0.10	0.02	2.00	1.00	–	1.50	94.60	[103]
50.62	46.91	0.38	0.02	0.09	0.08	0.28	0.18	1.29	–	–	0.00	97.91	[104]
57.37	38.63	0.77	0.03	0.07	0.15	0.39	0.49	–	0.61	–	1.04	96.77	[105]
48.45	34.75	1.28	0.03	0.85	–	0.02	2.40	0.85	0.09	–	–	84.48	[106]
58.52	35.54	1.15	1.24	0.19	0.06	0.25	0.05	0.04	0.09	–	2.74	95.21	[107]
63.51	29.68	1.22	0.48	0.48	0.30	0.14	1.79	0.66	–	–	1.95	94.41	[108]
58.16	37.63	0.79	0.17	0.19	0.35	0.09	0.08	1.13	0.41	–	0.93	96.58	[109]
54.3	38.3	4.28	0.39	0.08	–	–	0.50	–	–	–	0.68	96.88	[110]
Volcanic ash													
47.40	18.52	10.04	7.90	6.04	0.34	2.58	1.07	1.62	0.64	0.01	2.21	75.96	[111]
40.48	12.90	17.62	11.83	8.33	–	3.60	1.67	–	1.37	–	1.60	71.00	[112]
73.68	14.69	2.63	2.02	0.28	0.03	2.27	3.88	–	–	0.06	2.39	91.00	[113]
44.95	17.32	9.49	12.36	4.20	0.01	3.00	1.39	–	–	0.00	6.72	71.76	[114]
46.48	14.74	12.16	8.78	8.73	–	3.39	1.27	2.31	0.63	–	1.32	73.38	[115]
47.40	18.56	10.04	7.90	6.04	0.34	2.58	1.07	1.62	0.64	0.01	2.21	76.00	[116]
46.96	17.81	9.74	10.97	2.46	0.84	3.29	1.57	–	–	–	–	74.51	[117]
65.20	14.9	3.50	3.20	0.60	0.00	3.80	3.70	0.70	–	–	3.90	83.60	[118]
46.50	19.28	11.22	8.50	5.48	0.14	2.70	3.61	1.88	–	–	0.66	77.00	[119]
44.95	16.91	9.47	14.59	3.70	0.20	1.34	1.35	–	–	–	4.30	71.33	[120]
47.40	18.57	10.04	7.90	6.06	0.34	2.58	1.07	1.62	0.64	0.01	2.21	76.01	[121]
Zeolite													
68.95	11.14	0.94	4.83	0.79	0.07	0.95	0.90	–	–	–	–	81.03	[122]
63.72	11.40	2.73	3.29	0.05	0.13	1.02	2.83	0.29	0.03	–	14.20	77.85	[123]
75.34	8.77	1.30	4.60	0.55	0.05	1.22	2.41	–	–	–	–	85.41	[124]
63.32	11.70	0.32	3.60	1.20	0.09	–	–	–	–	–	8.49	75.34	[125]
64.70	11.21	1.38	2.08	0.79	0.03	–	3.78	–	–	–	8.00	77.29	[126]
63.32	11.70	0.32	3.60	1.20	0.09	–	–	–	–	–	4.49	75.34	[127]
68.80	10.70	0.72	2.54	0.83	0.22	1.55	1.44	–	–	–	12.78	80.22	[128]
62.78	12.20	2.37	5.09	2.65	0.01	0.42	0.74	–	0.05	0.05	12.36	77.35	[11]
67.44	10.80	0.84	1.24	0.33	0.47	3.71	0.19	–	–	–	–	79.08	[129]
69.20	15.28	3.01	2.24	1.40	0.45	2.20	2.10	–	–	–	4.12	87.49	[130]
67.79	13.66	1.44	1.68	1.20	0.50	2.04	1.42	–	–	–	10.23	82.89	[131]

[64,83,84]. Therefore, the present study is aimed to know the range of most positive reflections of SCMs on physical, mechanical, durability, and microstructural properties of cement composite materials due to its doses, types, and chemical reactions through compressively reviewing different literature.

1.2. Chemical composition of supplementary cementitious materials

1.2.1. Chemical composition of natural supplementary cementitious materials

The pozzolanic reaction of natural SCMs mainly depends on their chemical composition, chemical reactivity index, and mineralogical composition [6]. Also, Setina et al. [85] reported as pozzolanic activity of pozzolana is strongly dependent on their chemical composition mostly on the amounts of reactive silica. As presented in Table 1, all reviewed natural SCMs satisfy ASTM C618 [86] requirements, by the addition of the values of sulfur dioxide (SiO₂), Aluminum oxide (Al₂O₃), and Iron oxide (Fe₂O₃) greater than 70% for natural pozzolanic materials added to concrete manufacturing. This is due to the reason SCMs are used to reduce the production cost of cement and environmental pollution, but as well those three oxides have the potential to actively react with free lime from

Table 2
Chemical composition of manmade supplementary cementitious materials used in various research.

Rise Ash/Biomass Ashes													
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Cl	LOI	SAF	References
62.00	31.50	1.79	0.48	0.39	–	–	–	–	–	–	0.71	95.29	[132]
88.84	0.80	0.39	1.78	0.92	0.35	1.10	2.80	0.04	0.61	–	2.02	90.03	[133]
90.60	1.70	0.70	0.10	0.80	–	–	2.40	–	–	–	6.00	93.00	[134]
83.10	2.15	1.10	4.70	1.50	1.20	0.10	2.96	–	2.05	–	1.13	86.35	[135]
89.91	0.13	0.95	2.75	0.30	0.83	0.01	2.75	–	–	–	2.99	90.99	[136]
92.80	0.15	0.17	0.70	0.77	–	0.08	3.35	–	1.07	–	–	93.12	[137]
91.15	0.41	0.21	0.41	0.45	0.62	0.05	6.25	–	–	–	0.45	91.77	[138]
86.90	0.24	0.10	1.03	0.34	0.14	0.11	2.11	–	–	–	1.53	87.24	[139]
66.12	14.99	7.16	2.57	1.19	0.26	0.54	3.52	1.13	1.14	–	9.34	88.27	[140]
78.34	8.55	3.61	2.15	–	–	0.12	3.46	0.50	1.07	–	–	90.50	[141]
77.25	6.37	4.21	4.05	2.61	0.11	1.38	2.34	0.58	0.59	–	–	87.83	[142]
71.11	4.85	6.80	4.04	–	–	2.25	3.89	0.40	0.39	–	–	82.76	[143]
Silica fume													
90.36	0.71	1.31	0.45	–	0.41	0.45	1.52	–	–	–	3.11	92.38	[144]
92.50	0.72	0.96	0.48	1.78	–	0.50	0.84	–	–	–	1.55	94.18	[145]
94.17	1.10	1.45	1.20	0.18	0.25	0.45	1.20	–	–	–	–	96.72	[146]
96.09	0.14	0.07	0.39	0.12	0.09	0.19	0.42	–	–	–	2.50	96.30	[147]
96.40	0.25	0.45	0.25	0.45	0.15	0.20	0.50	–	–	–	–	97.10	[148]
91.80	0.54	1.92	0.70	0.49	0.35	0.68	1.20	–	–	–	1.67	94.26	[149]
91.57	0.38	0.15	0.32	4.05	–	0.55	2.58	–	–	–	1.68	92.10	[150]
99.80	0.11	0.09	0.40	0.20	–	0.20	0.50	–	–	–	3.50	100	[151]
90.21	0.12	0.15	0.30	0.73	0.01	0.46	1.51	–	–	–	–	90.48	[152]
85.04	0.97	1.04	1.63	1.20	1.22	0.48	0.36	0.21	–	–	2.03	87.05	[153]
93.60	1.32	0.37	0.49	0.97	0.10	0.31	1.01	–	–	–	–	95.29	[122]
90.82	0.47	2.26	0.52	1.55	0.68	1.02	1.95	–	0.12	0.22	–	93.55	[154]
93.60	1.32	0.37	0.49	0.97	0.10	0.31	1.01	–	–	–	–	95.29	[155]
93.67	0.83	1.30	0.31	0.84	0.16	0.40	1.10	–	–	–	2.10	95.80	[156]
Fly ash													
51.59	23.78	6.58	4.30	0.49	3.05	1.09	3.05	1.03	–	–	–	81.95	[157]
55.23	25.95	10.17	1.32	0.31	0.18	1.59	1.59	–	–	–	5.25	91.35	[158]
48.22	29.27	1.19	9.60	2.56	–	1.84	1.14	0.26	0.18	–	5.78	78.68	[97]
55.40	20.76	11.26	3.88	1.38	–	0.84	2.09	–	–	–	–	87.42	[159]
52.90	33.20	5.23	2.92	1.06	0.73	0.72	1.20	1.17	–	–	–	91.33	[160]
57.20	28.81	3.67	5.16	1.48	0.10	0.08	0.94	–	–	–	–	89.68	[161]
55.27	26.72	6.66	2.35	0.81	0.47	–	3.01	1.89	1.95	–	3.20	88.65	[162]
50.96	25.88	8.25	2.15	2.60	0.65	1.26	2.65	1.36	0.35	–	3.20	85.09	[84]
51.45	26.00	7.65	3.58	1.71	0.93	0.10	3.84	–	–	–	4.85	85.10	[163]
54.20	27.17	6.23	6.89	1.16	0.11	0.17	0.67	1.79	0.97	0.01	3.65	87.60	[164]
54.70	29.00	6.74	1.29	0.80	0.10	1.88	–	–	–	–	2.72	90.44	[165]
57.80	26.30	6.20	1.60	0.80	0.30	–	3.00	1.30	0.10	–	–	90.30	[166]
53.01	27.89	8.71	4.23	1.84	0.96	0.58	1.63	–	–	–	1.15	89.61	[167]
57.01	20.96	4.15	9.79	1.75	–	2.23	1.53	0.68	–	–	1.25	82.12	[168]

clinker to produce calcium silicate hydrate (C–S–H) and calcium aluminate silicate hydrates (C–A–S–H) which is the crucial compound that improve strength, durability and make dense microstructure of cement composite materials. In addition to that increasing the sum of SiO₂, Al₂O₃ and Fe₂O₃ oxides increases the strength, mainly increasing of strength caused by SiO₂. That is because SiO₂ is the most important oxide which can improve the pozzolanic reaction in pozzolana [87].

1.2.2. Chemical composition of artificial supplementary cementitious materials

As presented in Table 2, all reviewed artificial supplementary cementitious materials satisfy ASTM C618 [86] requirements of addition for the values of sulfuric dioxide (SiO₂), Aluminum oxide (Al₂O₃), and Iron oxide (Fe₂O₃) greater than 70% for pozzolanic materials added to concrete manufacturing and also can see as the summation of three oxides SiO₂, Al₂O₃, and Fe₂O₃ of most of the artificial supplementary cementitious materials are more greater than the natural SMCs, that is also known as the summation of those three oxides can significantly play important role in the pozzolanic reaction. Hence increasing the sum of those three oxides significantly increases the strength and durability of cementitious materials [87].

2. Natural supplementary cementitious materials

Natural SCMs are natural pozzolana from the natural sedimentation of volcanic ash or lava that involves active silica, used as cementitious materials when combined with free lime [169,170]. Hence using of SCMs of natural pozzolana in concrete mixtures contribute a lot of significance in the fresh and hardened properties of concrete, enhancing workability, reducing the heat of hydration, lower permeability, improve ultimate strength and durability [171–185]. Also, increasing the content of natural pozzolana in concrete increases the chloride migration coefficient [186], increases sulfuric acid resistant [120,187–189], and decreases permeability & water

Table 3
Effect of bentonite on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding bentonite comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,5,10,15,20,25	0.40	0,7,28,56	15	7,28, 56	15	7,28, 56	–	–	Increase	Decrease	[208]
0,10,15,20,25,30,35	0.5	7,28,180	0	0,10, 15,20, 25,30, 35	15	7,28, 180	–	–	–	–	[200]
0,5,10,15,20	0.48	7,28	5	7,28	5	7,28	5	7,28	–	–	[209]
0,5,10,15,20	0.47	7,28	5	7,28	5	7,28	5	7,28	–	–	[210]
0,5,10,15,20	0.50	28,56,90	15	28,56,90	15	28,56,90	15	28,56,90	–	Decrease	[204]
0,10,15,20	–	28	15	28	15	28	–	–	–	–	[211]
0,5,10,15,20	0.53	0,3,28,90	15	90	15	90	–	–	Decrease	Decrease	[96]
0,5,10,15,20	0.40	0,7,28,56,90	15	56,90	–	–	–	–	Increase	–	[212]
0,5,10,15	0.40	0,3,7,28	10	28	10	28	10	28	–	–	[213]
0,3,6,9,12,15,18,21	0.58	3,7,28,56	15	56	–	–	–	–	Decrease	Decrease	[214]

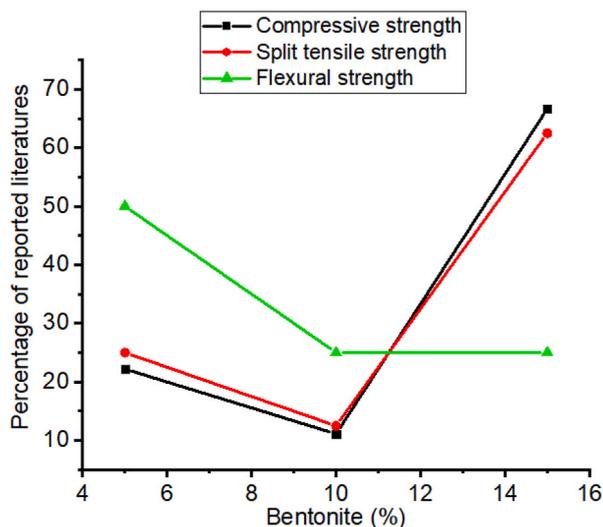


Fig. 1. Summary from Table-3 that most researchers reported on the influence of bentonite doses for optimum compressive strength, split tensile strength, and flexural strength.

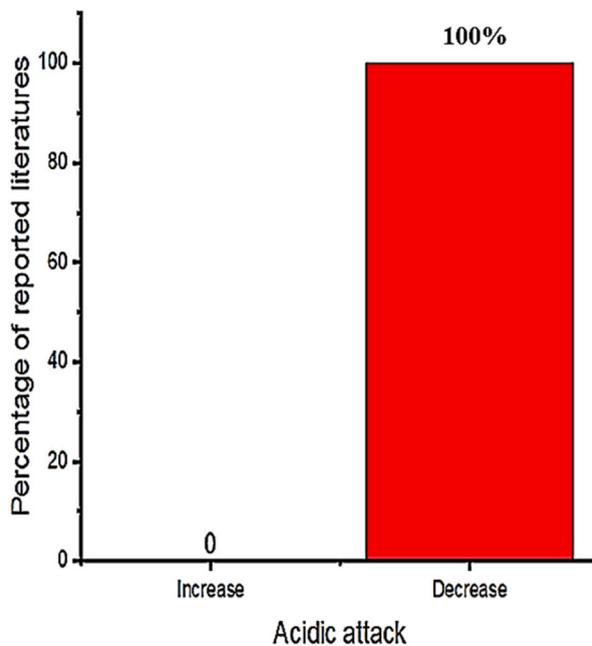


Fig. 2. Summary from Table-3 that most researchers reported on the influence of bentonite on acidic attack.

absorption which can improve the long-term strength gain of concrete [90,96,190–196].

2.1. Bentonite

Bentonite is alumina-siliceous material [97], mainly plastic clay consisting of 87% earth minerals with montmorillonite and fulfill pozzolanic properties. There are two types of bentonite namely, swelling sort/sodium bentonite and non-swelling sort/calcium bentonite [176,197]. Using bentonite in a concrete mixture reduces the contents of portlandite which is mainly due to the hydration reaction between cement and bentonite. In most cases, adding bentonite in concrete by replacing cement content have the ability to consume more portlandite compared with kaolin replacement in a concrete mixture [198]. Hence, employing bentonite in cementing material improve strength and durability by enhancing the resistance to acidic attack of cement matrix [199–206]. That is more presented in Table 3 as many researchers found optimum strength by using 5–15% of bentonite as a cement substitute in cement composite. Also mixing bentonite in concrete, improve concrete bleeding and cohesiveness of concrete in low-intensity level [207].

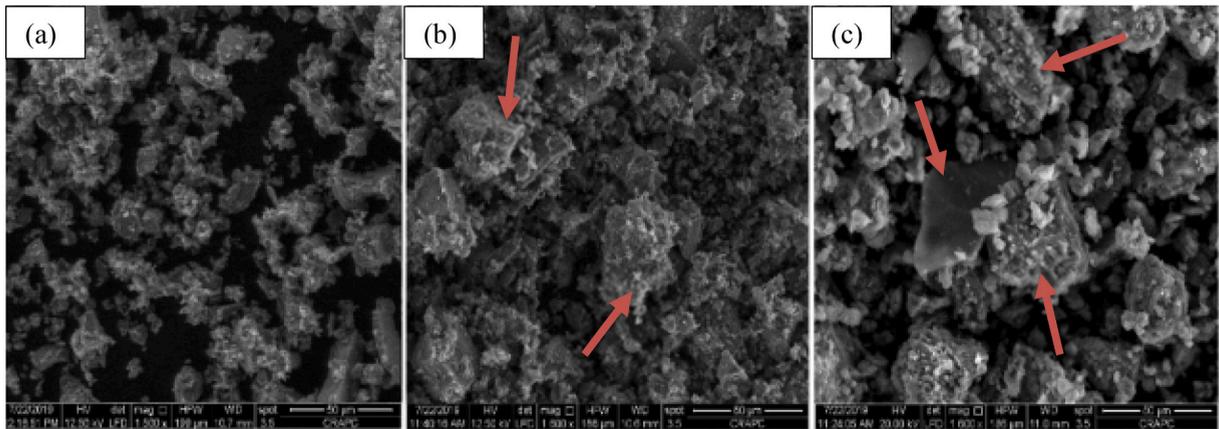


Fig. 3. Microstructure of cement composite materials (a) with OPC, (b) and (c) OPC with bentonite by [227].

Employing bentonite improves the strength and durability of concrete in construction works [174,204,209,210,215]. Specifically incorporating bentonite in concrete increases compressive strength compared to the control mixture [212,216,217]. That is as presented in Fig. 1 most researchers reported the incorporation of bentonite in cementitious material significantly enhances strength, specifically using 15% of bentonite replacement can highly improve compressive and splitting tensile strength, also 5% of bentonite addition highly improves flexural strength. Besides these, Fig. 2 shows the inclusion of bentonite in cementitious materials reduces acidic attack by enhancing the resistance of chloride penetration and sulfate resistance compared to reference concrete without bentonite [96,204,218,219]. This is mainly due to the amorphous silicate matrix actively reacts with Portlandite to form secondary C–S–H gel that improves the microstructure and strength of the final hydrated cement matrix, which is mostly dependent on the hydration reaction of pozzolana and cement phase [107,220–224].

In addition to these, the mixture of concrete that incorporates bentonite reflects a much denser microstructure compared to the reference mixture [225]. As shown in Fig. 3a–c, cementitious composite materials without bentonite have small particles having many pores between each other; however, the samples with SCMs of bentonite have large-sized particles, more dense, and very low pores between the particles. This means, employing bentonite significantly forms a dense structure and lower porosity compared to without bentonite. That is because of the dissolution of montmorillonite and the production of secondary minerals C–S–H gel in concrete containing bentonite [226].

2.2. Kaolin

Kaolin is natural pozzolana require calcination to form reactive pozzolana at a temperature between 700 and 1200 °C. So calcined kaolin improves the strength, and durability of Portland cement concrete and other cement composite materials [8,101,180,193,228–230]. As presented in Table 4 most researchers employed 10–25% of kaolin in cementitious materials to improve strength, specifically as shown in Fig. 4 most of the literature reported adding 15% by mass of cement can radically increase compressive strength, split tensile strength, and flexural strength. This is because of two actions, firstly pore filling ability of kaolin and secondly through the active pozzolanic reaction of kaolin with calcium hydroxide which can form an extra crystalline nucleus that can refine the hydrated gel structures [231].

As shown in Fig. 5a–b employment of kaolin in cementitious materials reduce water absorption and reduce acidic attack by filling an air-void matrix. This is due to the kaolin micro-filling effect of the pores of cement composite materials that reduce the migration of water or acids to the matrix. Also, Karahan et al. [237] reported as increasing meta-kaolin doses reduces porosity and water absorption. This is because, the pozzolanic reaction that can alter the microstructure of concrete with the chemistry of hydration reaction by consuming free lime and instead produces secondary calcium silicate hydrate (C–S–H) which can improve strength and durability [195], and also by its filler and pozzolanic effect [238]. Similar observation with M. A. Elahi et al. [49] as the inclusion of kaolin in cement composite enhances the sulfate resistance, which is by replacing kaolin from 5 to 25% to a mass of cement. Besides these, employing kaolin in cementitious materials improves chloride ion penetration due to the positive effect of kaolin in the reduction of porosity and water [236].

As presented in Fig. 6a the microstructure of plane cementitious materials has a nonuniform arrangement, high capillary pores, and also there is a high micro gap between cement paste and aggregates, that is maybe because of the collection of free lime crystal in the transition zone of interfacial [239]. As shown in Fig. 6b–c, the image of the cement composite sample without kaolin reflects not agglomerated particles having big and many pores, however in the samples of cementitious composite materials with kaolin can see dense and compacted structures having low pores. Hence replacement of kaolin to cement composite material reveals a denser microstructure with low porosity compared to the plane cementing material. This is due to the micro-filling ability of ultrafine kaolin particles which can make dense microstructures and fill the pore that exists in between aggregates and cement paste.

Table 4
Effect of kaolin on some of the mechanical properties and durability recorded by different researchers.

	Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding kaolin comparing with control mixtures		References
				Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
∞	0,10,20,30,40,50	–	7,14,28	10	7,14,28	10	7,28	10	7,28	–	–	[232]
	0,2.5,5,7.5,10	0.35	7,14,28	10	7,14,28	–	–	–	–	–	–	[233]
	0.5,10,15,20	0.32	7,28	15	7,28	15	28	15	28	–	–	[110]
	0.5,10,15,20	0.37	3,28,90	15	28,90	–	–	0	90	Decrease	–	[234]
	0.5,10,15,20	0.32	7,28	15	7,28	15	28	15	28	–	–	[110]
	0.5,10,15,20,25,30	0.45	3,7,28	25	3,7,28	–	–	–	–	–	Decrease	[105]
	3,5,10	0.53	7,28,60,90	10	7,28,60,90	10	7,28,60,90	–	–	Decrease	–	[61]
	0.10,20,30	0.50	2,28,90	20	2,28,90	–	–	–	–	–	–	[235]
	0,10,20,30,40,50	0.50	7,56,90,500	40	7,56,90,500	40	7,56,90,500	–	–	–	–	[107]
	0,5,10,15	0.50	7,28	15	7,28	–	–	15	7,28	–	–	[193]
	0,5,10,15,20,25	0.55	7,28	15	7,28	–	–	–	–	Decrease	–	[102]
	0,30	0.50	2,7,28,90	0	2,7,28,90	–	–	–	–	–	Decrease	[236]

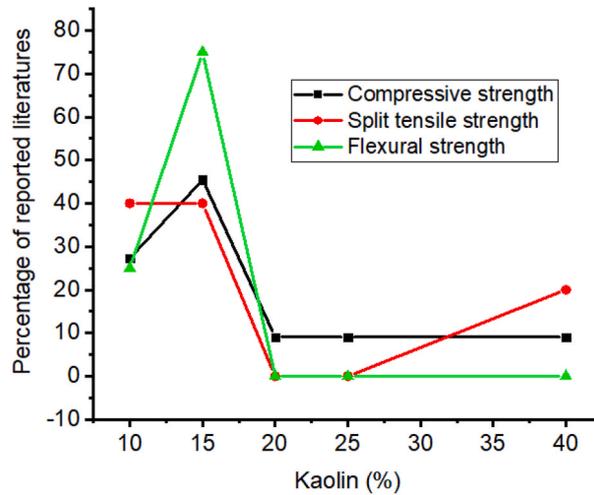


Fig. 4. Summary from Table-4 that most researchers reported on the influence of kaolin doses for optimum compressive strength, split tensile strength, and flexural strength.

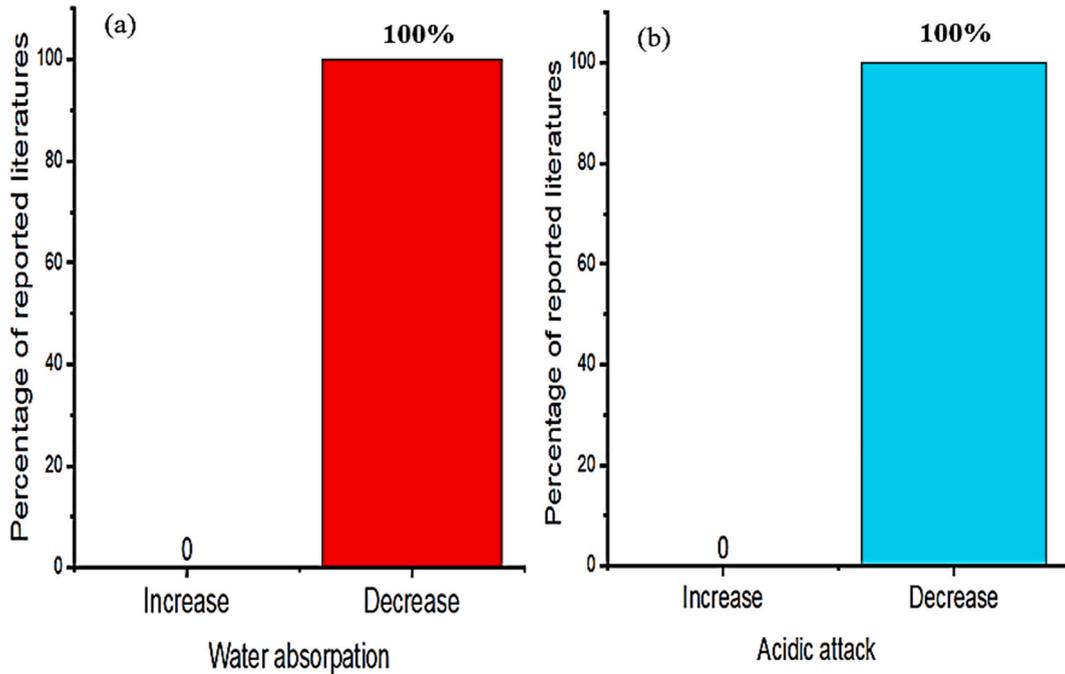


Fig. 5. Summary from Table-4 that most researchers reported on the influence of kaolin on (a) water absorption and (b) acidic attack.

2.3. Volcanic ash

Volcanic ash is natural pozzolanic material, that occurred during volcanic eruptions when magma or molten rock and solid rock shatter separated form fine particles of clay to the size of sand [240]. As presented in Table 5 employment of 5–20% volcanic ash improves the mechanical properties and durability of cementing materials. That is due to volcanic ash actively reacting with free lime (calcium hydroxide) and due to the hydration of cement, which is amorphous silica reacts in volcanic ash react with lime and form cementitious material C–S–H gel, it is crucial for the improvement of concrete durability, enhances strength, and lessen the rate of heat liberation important for mass concrete [241]. Also adding volcanic ash to cement composite enhances workability, reduces porosity [111], and significantly reduces concrete/cement composite production costs [242,243]. Generally, from the observation of many literatures, partial substitution from 5 to 20% of volcanic ash is beneficial for the improvement of workability, compressive strength, and durability in addition to making economical and environmentally friendly cement composite materials, which is mainly due to its

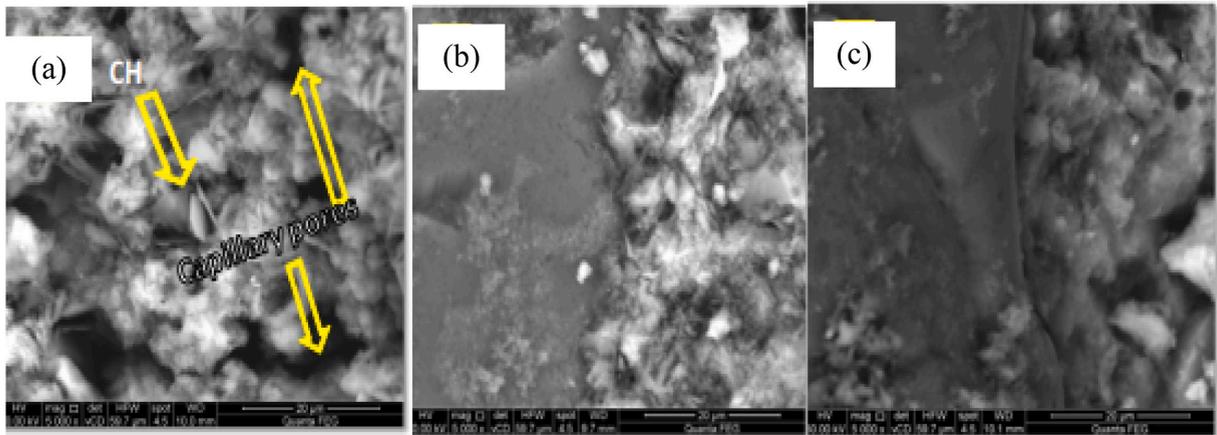


Fig. 6. Microstructure of cement composite materials (a) with OPC, (b) and (c) OPC with kaolin by Ref. [239] permission Elsevier.

high pozzolanic reactivity with portlandite in a cement.

The employment of volcanic ash actively reacts in cement hydration reactions to form secondary C–S–H gel which significantly improves strength [246]. This is more shown in Fig. 7 as most of the literature found the optimum compressive strength at 20% addition of volcanic ash to cement composites. Also as presented in Fig. 8 many researchers reported as the employment of volcanic ash reduces water absorption. That is because the use of volcanic ash in cement composite increase the densification of cement slurries that protects the penetration of water [246,249].

2.4. Zeolite

Zeolite can be used in lime mortar and concrete which is formed from a change of volcanic ash, tuff, and others. It is used in many cement industries over the world as a clinker partial substituent. Most of the effectiveness of zeolite in cementitious material significantly can reduce chloride ion penetration to concrete matrix [80,127]. This is mainly due to the interlocking and micro-filling ability of zeolite particles through having higher surface area and active pozzolanic reaction with free lime that can lessen the capillary pores in concrete/mortar matrix, hence reducing the penetration of chloride ions.

Also, the inclusion of zeolite in cementitious materials improves concrete mechanical properties, especially compressive strength, and durability [123,126,250–252]. As presented in Table 6 using 7.5–30% of zeolite in cementing materials highly enhance strength and durability, however as shown in Fig. 9, many researchers found employing 10% of zeolite in cementitious materials can give optimum compressive strength, split tensile strength, and flexural strength. That is because zeolite actively reacts with free calcium hydroxide to form C–A–S–H and C–S–H which are crucial compounds to improve the mechanical properties of concrete [11,126]. Also, Sicakova et al. [253] studied the effect of blinding zeolite on the long-term properties of cement-based composites for building material and found as incorporating zeolite in concrete increase the long-term compressive strength (three years) and density of concrete compared to control concrete mix.

The replacement of cement with natural zeolite reduced the water absorption and chloride diffusion coefficient of concrete [125]. Besides this inclusion of zeolite in concrete increase sulfate resistance, and reduce water permeability compared to the reference concrete mixtures [128]. Hence as presented in Fig. 10a–b many researchers reported as adding zeolite in cementitious materials decreases water absorption and acidic attack, which is primarily due to the active pozzolanic reaction of zeolite in the hydration process. This reduction of water absorption is one of the factors that indicate improvement in durability [11]. A similar observation with Samimi et al. [258] investigated the influence of zeolite on compressive strength and chloride ion resistance. And found as employing zeolite in concrete ultimately enhances electrical resistivity, hence significantly improves the durability of concrete by reducing chloride ion migration.

Replacement of zeolite to cement ratio is beneficial in enhancing crack width control ability and reduces shrinkage of cementitious materials [259]. As presented in Fig. 11a can observe from cementitious material without zeolite many pores, cracks, and low dense even hair-like structures; which can reduce the durability of the cementing materials by allowing penetration of water and acids, but as shown in Fig. 11b, the sample with zeolite can not see such hair-like structures and many pores. Hence employing zeolite can reduce the occurrence of cracks, make dense microstructure and reduce pores. This is because of the pozzolanic reaction of zeolite with free calcium hydroxide and form additional C–S–H gel that is responsible for making denser microstructure and improve the durability of cementitious materials [260].

Table 5
Effect of volcanic ash on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding volcanic ash comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,5,10, 15	0.30	28,56	5	28,56	-	-	-	-	-	-	[241]
0,10,20,30	0.48	7,28,90	10	90	-	-	-	-	Decreases	-	[111]
0,20	0.40	7,28,90	20	90	-	-	-	-	-	-	[244]
0,15,30	0.38	1,7,28,56,90,180	15	90,180	-	-	-	-	Increases	-	[245]
0,10,20,30	0.45	7,14,21, 28	20	21,28	-	-	-	-	-	-	[246]
0,10,20,30,40, 50	0.35	28	20	28	-	-	-	-	-	-	[243]
0,10,20,30	0.48	7,28,91	30	28,90	-	-	-	-	-	-	[247]
0,5,10, 15,20	0.35	7,28,120	5	7,28, 120	-	-	-	-	-	-	[248]
0,10,20,30	-	1,7,14,28,90,180	10	90,180	10	28,90,180	10	28,90,180	Decreases	-	[116]

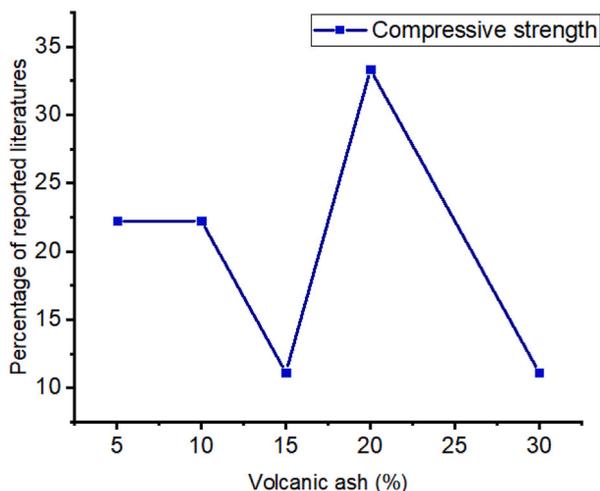


Fig. 7. Summary from Table-5 that most researchers reported on the influence of volcanic ash doses for optimum compressive strength.

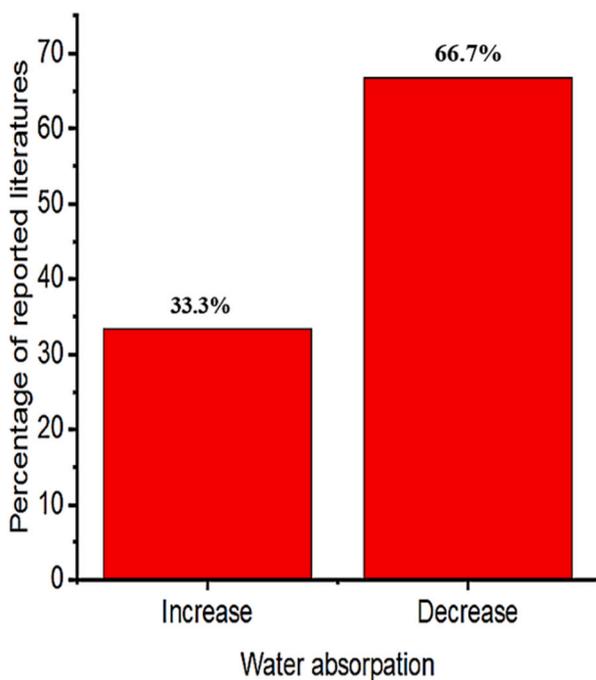


Fig. 8. Summary from Table-5 that most researchers reported on the influence of volcanic ash on water absorption.

3. Artificial supplementary materials

3.1. Fly-ash

Fly ash is a coal-fired by-product from thermal power plants [262,263], mainly consisting of a high proportion of aluminum phase and predominantly spherical particles, which enhances the fluidity of the freshly mixed cement paste [260]. Also, the spherical shape of fly ash increases the volume of the structure due to the lower density of fly ash particles [229,264], and lessens the development of hydration products [265].

Raghav et al. [158] reported as fly ash needs activation due to two factors. First, the glassy surface layer of glass beads is dense, chemically stable, and preserves the inside constituents, which are porous, spongy, and amorphous. Second, the silica–alumina glassy chain of high Si, Al, and low Ca is stable; the chain must be decomposed to actively react with free lime that exists in cement. Consumption of free lime increases with increasing the fineness of fly ash [266]. So mechanical grinding, thermal activation, and chemical

Table 6
Effect of zeolite on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding Zeolite comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,10,20,30,40	0.35	42	10	42	–	–	–	–	–	–	[254]
0,10,20,30	0.40	7,28	10	7,28	–	–	–	–	–	Decrease	[255]
0,10,15	0.35,0.40,0.45,0.50	7,28, 90,270	10	7,28, 90,270	10	90	–	–	Decrease	Decrease	[256]
0,2,5,5,7,5,10	0.45	7,28	10	7,28	–	–	–	–	Decrease	–	[194]
0,5,10, 15,20	0.50	3,7,28,90	15	28,90	–	–	15	28,90	Decrease	Decrease	[127]
0,10,20,30	0.40	2,7,28,60,90,180	10	180	–	–	10	180	Increase	–	[11]
0,5,10, 15	0.48	28	15	28	15	28	10	28	–	–	[131]
0,30,40	0.30	28,56	30	56	0	28,56	–	–	–	Decrease	[80]
0,7.5,15,22.5,30	0.38	7,28, 90	7.5	90	–	–	–	–	Increase	–	[257]

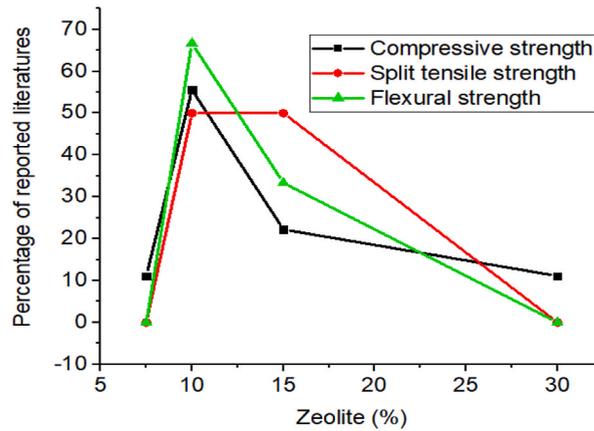


Fig. 9. Summary from Table-6 that most researchers reported on the influence of zeolite doses for optimum compressive strength, split tensile strength, and flexural strength.

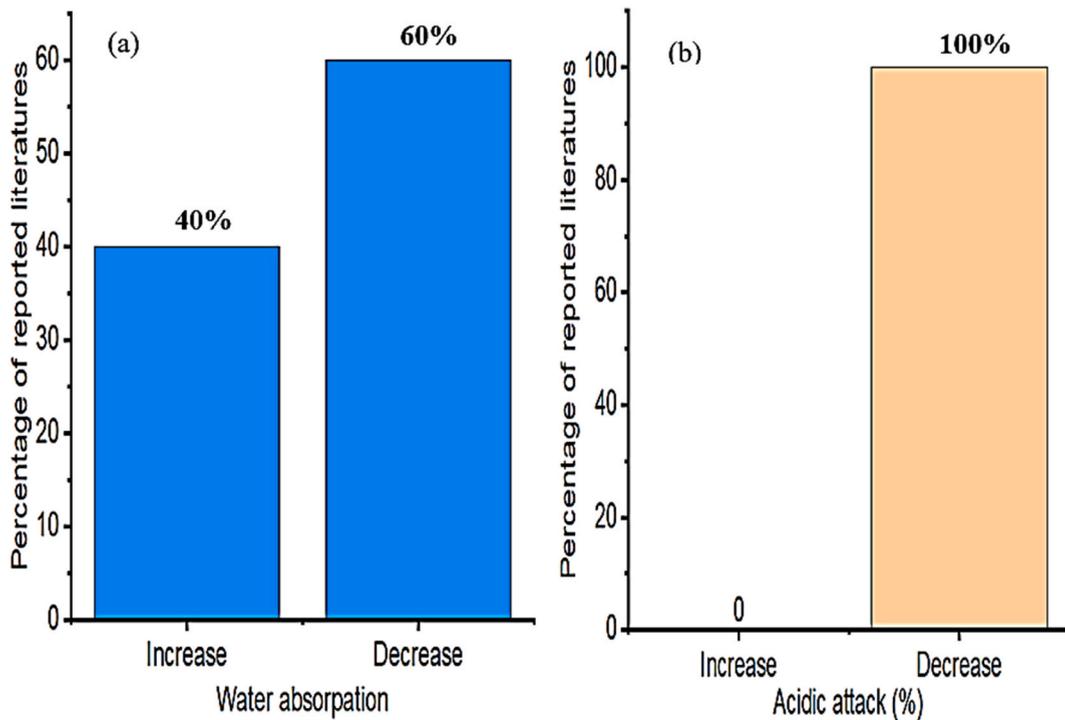


Fig. 10. Summary from Table-6 that most researchers reported on the influence of zeolite on (a) water absorption and (b) acidic attack.

activation accelerate. Thus the significant level of replacement of Portland cement by fly ash is not only advantageous to the concrete but also minimizes the consumption of cement, and thereby decreases the effect of greenhouse gas [267,268].

Also, the replacement of fly ash in ordinary Portland cement with partial replacement green has a positive effect on the mechanical and durability properties of cement composites [265,269,270], this is more similar to the result of most literature presented in Table 7, employing 5–30% of fly ash increase strength of cementitious materials while at higher replacement ratios negatively affect; moreover, the size of fly ash alters the properties of composites.

Also, the inclusion of fly ash improves the workability, durability, splitting tensile strength, and compressive strength of cementitious materials [74,274,280–284]. Specifically, as most literature studied shown in Fig. 12 addition of 10% of fly ash significantly improves the compressive, split tensile, and flexural strength of cementitious materials. Also as shown in Fig. 13a–b employment of fly ash highly reduce water absorption and acidic attack of cementitious materials compared with plane one. This is due to the fly ash micro filling ability reduces the pores and increase the density of cementitious materials which can protect the penetration of water and acids into the cement structural matrix [81,162,285].

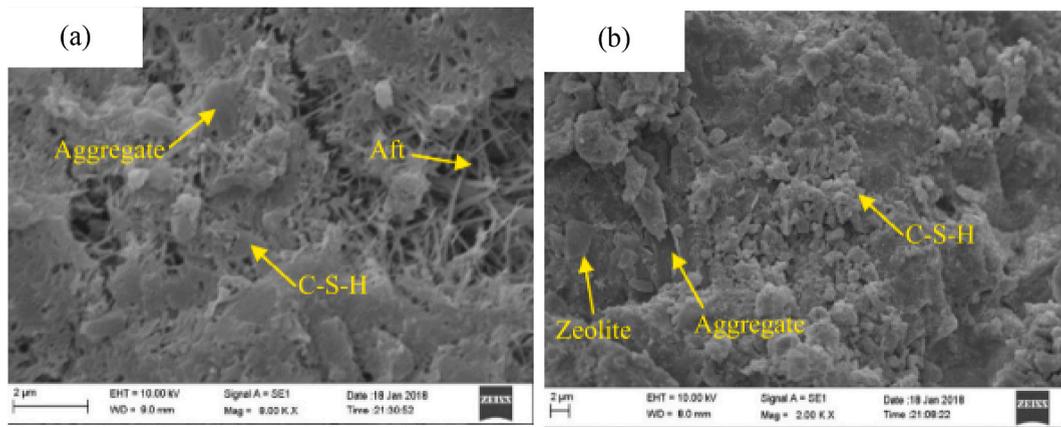


Fig. 11. Microstructure of cement composite materials (a) with OPC and (b) OPC with zeolite by Ref. [261] permission Elsevier.

3.2. Biomass ash

Sugarcane Bagasse Ash is biomass ash and a by-product of making juice from sugar cane by crushing the stalks of the plants [13], that can be considered as pozzolanic material and potentially can lessen free $\text{Ca}(\text{OH})_2$ in a cement matrix, which is owing to the pozzolanic reaction. Rice husk ash is another biomass ash that is highly reactive pozzolanic material from agro-waste by the combustion of rice husk [264,286].

As presented in Table 8 employing biomass ash improves strength and durability, especially many researchers reported using 10–20% biomass ash in cement composite can give optimum strength. That is due to the pozzolanic reaction of biomass ash favors the formation of secondary C–S–H gel and due to the amorphous state of reactive silica which can significantly enhance the strength and durability of concrete [58,158,195,287–295].

Employing biomass ash mostly improves the compressive and splitting tensile strength of concrete compared to concrete without biomass ash [294,296,298,303–305]. Mostly as much of the literature reported shown in Fig. 14, 10% of biomass ash significantly improves the compressive, splitting tensile, and flexural strength of cement composites.

As presented in Fig. 15a and b, employing biomass ash reduce water absorption and acidic attack of cementitious materials, specifically, rice husk ash in concrete reduces water absorption and chloride ion migration to the concrete [306]. That is because nano-silica in rice husk ash improves the formation of higher hydration products which fills the pores and makes denser microstructure which can reduce water absorption of concrete [51,136,307]. Also, the enhancement of durability of cementitious material reflected because of biomass ash from rice husk greatly can resist the migration of chloride ions, which means in another direction reduces the occurrence of corrosion in reinforced concrete [299].

Furthermore, Raghav et al. [158] reported as the addition of biomass ash decreases the acid attack, chloride diffusion, and corrosion rate of embedded steel rebar, especially, the unreacted silica in sugarcane bagasse ash acts as a pore filler, which can decrease porosity and voids in the concrete. So the reduction of porosity increases the resistance to chloride penetration and reduces the corrosion rate of steel rebar. However due to fineness of sugarcane bagasse ash highly increases the amount as cement replacement leads to high water demand, which can reduce workability of cement composite materials. The same observation with Tayeh, Hadzima-Nyarko et al. [308] as employing biomass ash, especially the agricultural waste of olive waste ash improves acidic and alkaline attack compared to the control concrete mixture.

Besides improving strength and durability, using biomass ash radically improve the microstructure of cement composites. As presented in Fig. 16a, cementing materials without biomass are not agglomerated structure though have many pores and stick-like structures that can allow the migration of water and acids which can reduce the durability of cementitious composite materials, however in Fig. 16b can observe cementitious materials with biomass ash which is highly dense microstructure, very fewer pores, and have uniformly structured matrix. This is very appreciable for the construction industry which requires high-performance of cementitious materials.

Generally, employing biomass ash from agricultural waste ash is beneficial for both technical and economical construction works. Hence it is mostly used for economic construction and for the reduction of environmental pollution [309–311].

3.3. Silica fume

Silica fume is an artificial pozzolanic admixture [312] as shown in Fig. 17, the production process of silica fume is de-dusting from an electric furnace due to the manufacturing of silicon, zirconium, and ferrosilicon [38,147,313–316]. Employing silica fume in cementitious materials reduces permeability which means increase durability, decreases workability, and improves compressive strength [74,147,313,317–319]. That is because silica fume particles are ultrafine and have a large surface area than cement particles which reduce workability by binding water in concrete/mortar, however, it refines the existence of pores and makes dense structure

Table 7

Effect of fly ash on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding fly ash comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,5,10,15,20	–	28,60,90	10	28,60,90	–	–	–	–	–	Decrease	[271]
0,10,20,30	0.45	7,28	30	7,28	–	–	–	–	–	–	[272]
0,10,20,30,40,50	–	7,14, 21,28	10	7,14,21, 28	10	7,14, 21,28	–	–	–	–	[273]
0,10,30	0.45	3,7,28	10	3,7,28	10	7,28	10	7,28	–	–	[274]
0,15,30,45	0.55	3,7,14,28	30	3,7,14,28	30	3,7,14,28	–	–	–	–	[275]
0,10,20	0.34	7,28	10	7,28	10	7,28	10	7,28	–	–	[276]
0.5,10,15	0.50	7,28, 56,90	5	7,28,56, 90	5	7,28, 56,90	–	–	–	–	[10]
0,10,30,50,70	0.30	28,56	30	28,56	30	28,56	–	–	Decrease	Decrease	[277]
0,5,10,15,20,25	0.50	7,28, 90, 180,	10	7,28,90, 180,	10	7,28, 90, 180,	–	–	–	–	[278]
0,5,10	0.65	28,100,130	5	100,130	–	–	–	–	Decrease	Increase	[279]

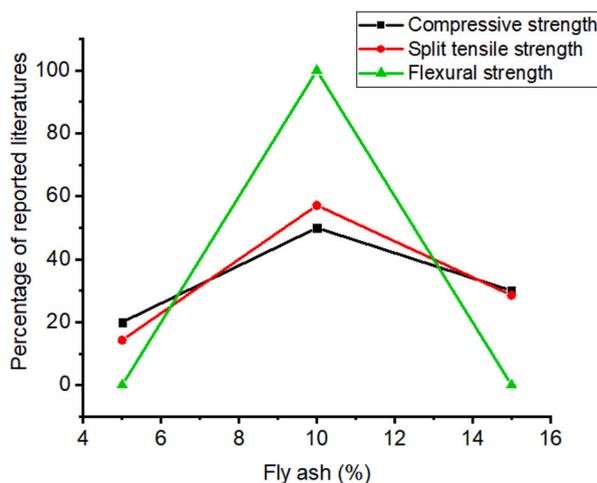


Fig. 12. Summary from Table-7 that most researchers reported on the influence of fly ash doses for optimum compressive strength, split tensile strength, and flexural strength.

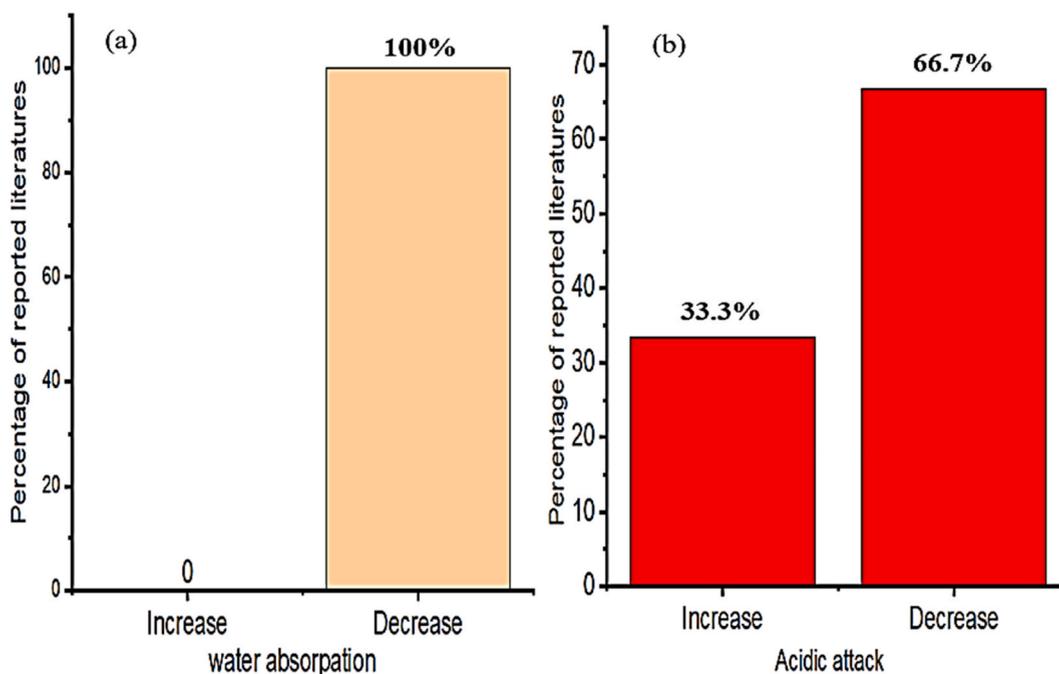


Fig. 13. Summary from Table-7 that most researchers reported on the influence of fly ash on (a) water absorption and (b) acidic attack.

that improve durability and strength. In addition to this, since silica fume is waste from metal industries used in cement composite materials can lessen environmental pollution and construction costs.

As presented in Table 9 many researchers found optimum strength and high durability by the addition of silica fume between 7 and 18% in cement composites, however, as shown in Fig. 18 most literature reported specific doses of silica fume of 10% by mass of cement which can give optimum compressive and split tensile strength. This mechanical property and durability of concrete improvement is due to the consumption of Ca(OH)_2 by pozzolanic reaction and high pore refinement [156,320–323]. Also increasing the contents of silica fume in cementitious material significantly reduces water absorption [148,324] and increases viscosity compared to the control mixtures [325]. This is due to the volume of void reduces by adding silica fume, because of the high level of specific surface area and high hydration reaction of silica fume [318]. Besides these, the inclusion of silica fume in cementitious material enhances the long-term corrosion resistance, and alkali-silica expansion, but also increases the carbonation depth in addition to refining the pores [314]. Moreover, recycling artificial SCMs from industrial waste conserves natural resource and prevent environmental pollution [326].

Table 8
Effect of biomass ash on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/ C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding biomass ash comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,5,10, 15,20	0.40	7,28, 90	10	28,90	-	-	-	-	Decrease	-	[295]
0,10	0.60	7,14, 28,56	10	7,14,28,56	10	7,14,28, 56	10	7,14, 28,56	-	-	[296]
0,10	0.60	7,14, 28,56	10	7,14,28,56	10	7,14,28, 56	-	-	-	-	[296]
0,10,20,30, 40,50	0.35	7,30, 60,90, 120, 150, 180	10	30,60, 90,120, 150,180	-	-	-	-	-	-	[297]
0,5,10, 15,20	0.55	7,14, 28	10	7,14,28	15	7,28	10	7,28	-	-	[298]
0,2,5,5, 7,5,10, 12,5, 15	0.60	3,7,28,90	10	7,28,90	10	7,28,90	10	7,28, 90	-	Decrease	[299]
0,5,10, 15,20	0.45	7,14, 28	10	7,14,28	10	7,14,28	-	-	-	-	[300]
0,5,10, 15,20	0.50	7,28	10	7,28	-	-	-	-	-	-	[141]
0,5,10, 15,20	0.45	7,14, 28,60	20	7,14,28,60	10	7,14,28, 60	-	-	Increase	Increase	[301]
0,5,10, 15,20,25	0.49	7,28, 90,180	10	7,28,90,180	10	28	-	-	-	Decrease	[143]
0,5,10, 15,20	0.50	7,28, 56	10	7,28,56	-	-	-	-	Decrease	Decrease	[302]

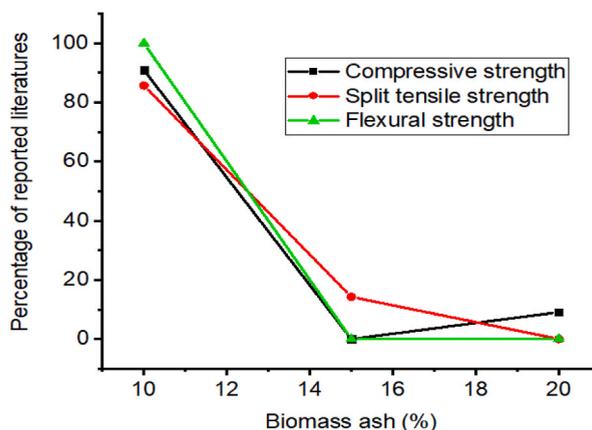


Fig. 14. Summary from Table-8 that most researchers reported on the influence of biomass ash doses for optimum compressive strength, split tensile strength, and flexural strength.

As shown in Fig. 19(a-c), can observe cementitious composite materials without silica fume have many capillary pores and are not well-dense structures compared to the ones with silica fume. So the incorporation of silica fume can make dense microstructure and highly reduce pores which is more observable in the plane cementitious material. This is because of the active pozzolanic reaction of silica fume with free lime to form secondary calcium silicate hydrate gel which is responsible for changing the microstructures of cementitious material to be more denser than the one without silica fume [155,332].

Generally, from the review of different literature partial substitution of artificial and natural SCMs are beneficial for the improvement of physical, mechanical, durability, and microstructural properties of cement composite materials due to their micro-filling ability, having large surface area and by pozzolanic reaction between the free lime and SCMs to produce secondary calcium silicate hydrate (C-S-H) which can improve different properties of cement composite materials. However using of 100% OPC may lack all those important roles of SCMs, since the specific surface area cement is smaller than SCMs and free lime in OPC can not get more

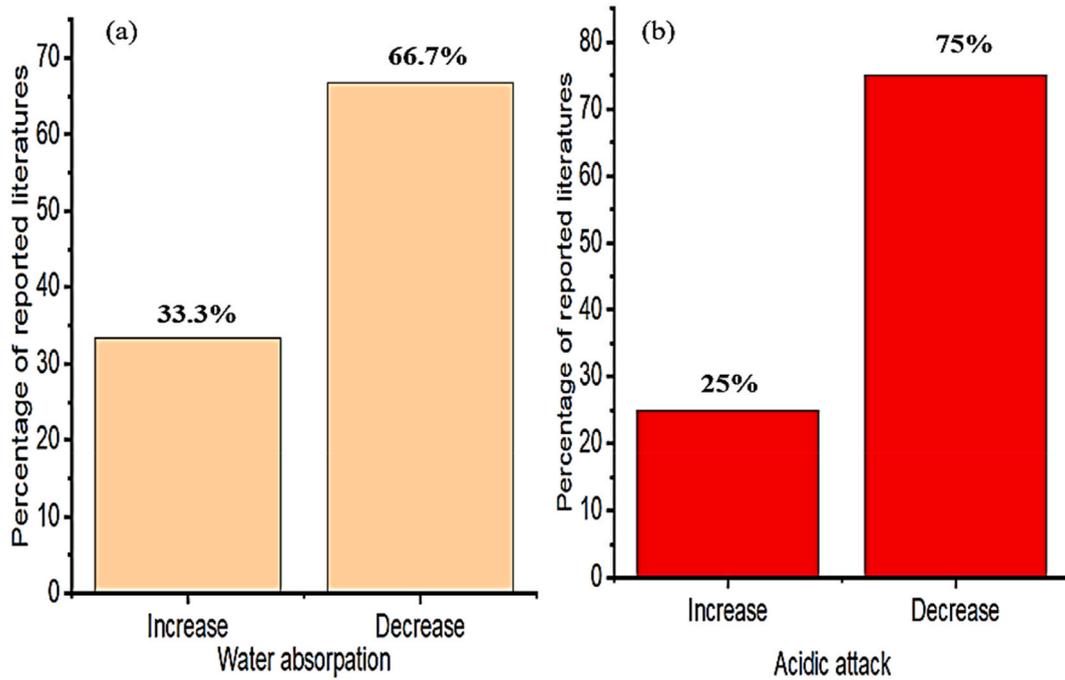


Fig. 15. Summary from Table-8 that most researchers reported on the influence of biomass ash on (a) water absorption and (b) acidic attack.

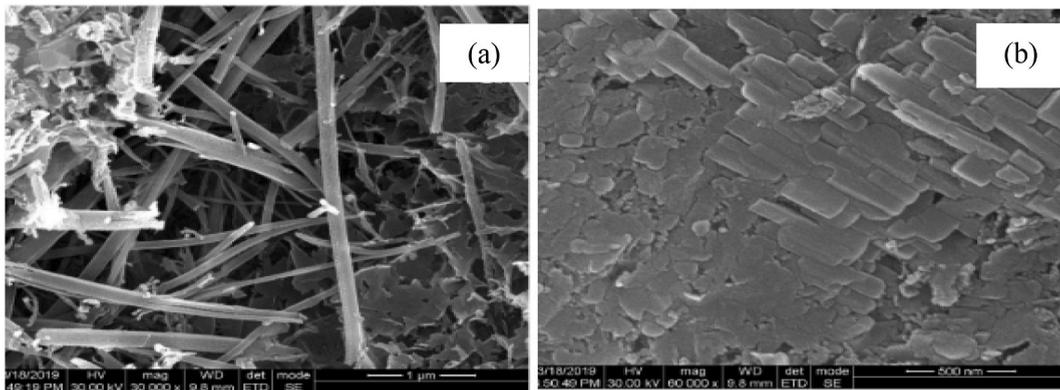


Fig. 16. Microstructure of cement composite materials (a) with OPC and (b) OPC with biomass ash by Ref. [288] permission Elsevier.

chances for the pozzolanic reaction to form additional C–S–H gel. In addition to this, using 100% OPC is costly and have an environmental problem, since its production requires much energy and releases more CO₂ to the environment compared to composite cement. But standing on all these benefits of SCMs in cement composite materials, in the practical aspect of construction works can see adding of SCMs materials beyond the researchers result, which may loss all the importance of SCMs in cement composite materials.

4. Conclusions

The review of the various studies reported the beneficial effects of adding SCMs in cement composite, by improving mechanical properties, enhancing durability, and making dense microstructure of cement composite materials. The following conclusions are made based on the comprehensive review of this study.

- Partial replacement of bentonite, biomass ash, and kaolin isolately by 15% and volcanic ash by 20% in cement composite materials can give optimum compressive strength and splitting tensile strength.
- Addition of fly ash, silica fume, and zeolite isolately in cement composite materials by 10% reflected optimum compressive strength and split tensile strength.

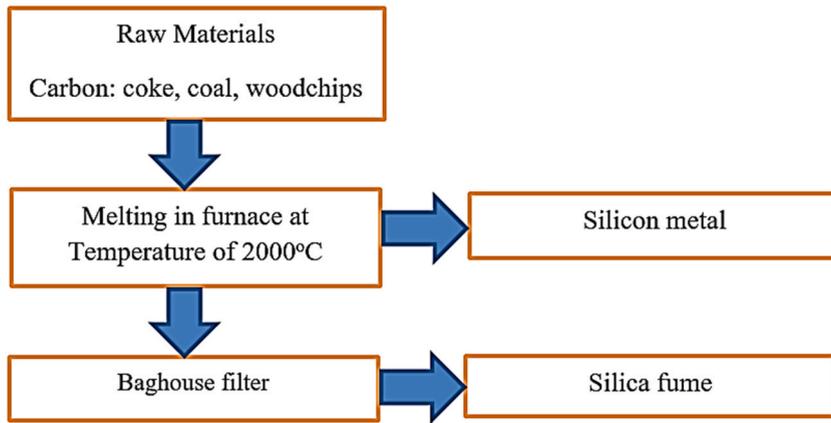


Fig. 17. Schematic diagram of silica fume production by Ref. [313] permission Elsevier.

Table 9

Effect of silica fume on some of the mechanical properties and durability recorded by different researchers.

Dose range	W/C	Curing time	Optimum compressive strength		Optimum split tensile strength		Optimum flexural strength		Durability of adding Silica fume comparing with control mixtures		References
			Dose (%)	Age (days)	Dose (%)	Age (days)	Dose (%)	Age (days)	Water absorption	Acidic attack	
0,5,10,15,20	0.36	7,28	15	7,28	10	7,28	15	7,28	-	Decrease	[327]
0,5,10,15,20	0.32	7,28,56,90	10	7,28,56,90	10	7,28,56,90	-	-	-	-	[312]
0,10,20,30,40	0.55	3,7,14,28	30	14,28	30	28	30	28	-	-	[328]
0,7,10	0.40	28	7	28	7	28	7	28	-	-	[329]
0,0.5,1,5,10,15	-	3,7,14,21,28	10	3,7,14,21,28	-	-	-	-	-	-	[330]
0,2.5,5,7.5,10	0.48	28	10	0,2.5,5,7.5,10	10	28	-	-	-	-	[331]
0,6,12,18,24	0.48	3,7,28,56	18	7,28,56	-	-	-	-	-	-	[332]
0,5,10	0.50	7,28,90	10	7,28,90	10	7,28,90	-	-	Decrease	-	[333]
0,3,6,9,12,15	0.36	28	12	28	12	28	-	-	-	-	[334]

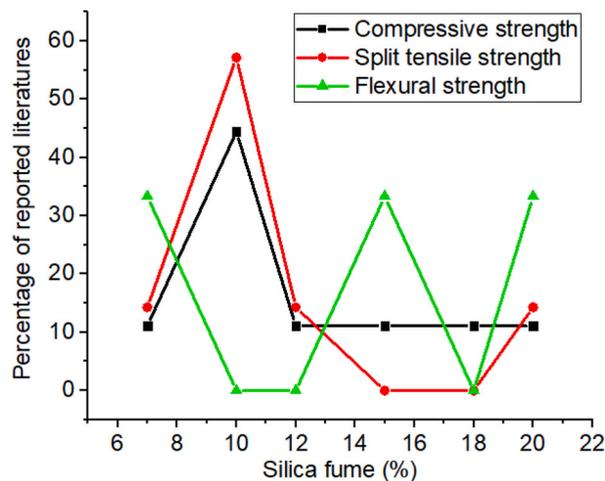


Fig. 18. Summary from Table-9 that most researchers reported on the influence of silica fume doses for optimum compressive strength, split tensile strength, and flexural strength.

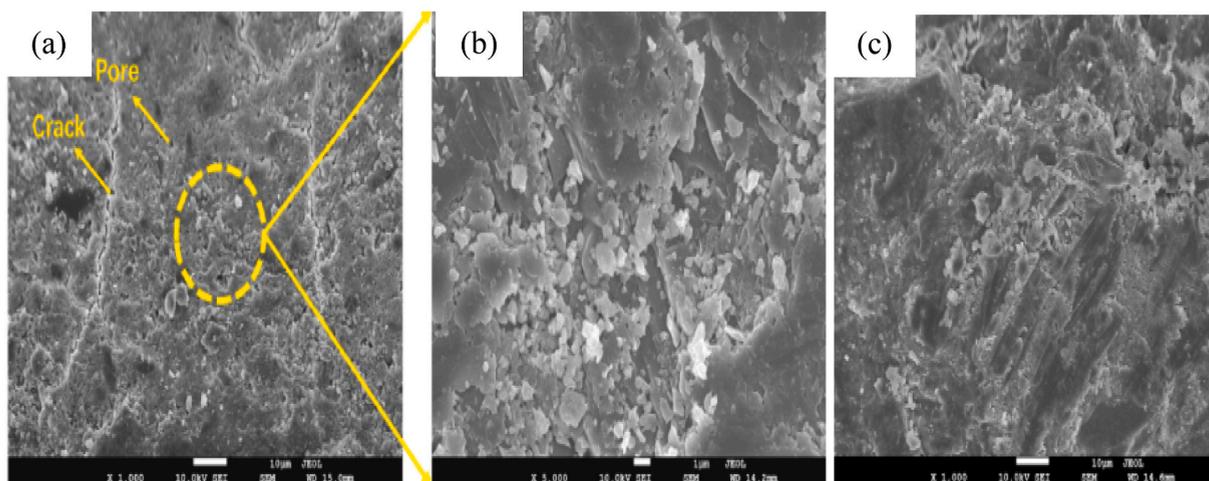


Fig. 19. Microstructure of cement composite materials (a), (b) by OPC and (c) OPC with silica fume by Ref. [331] permission Elsevier.

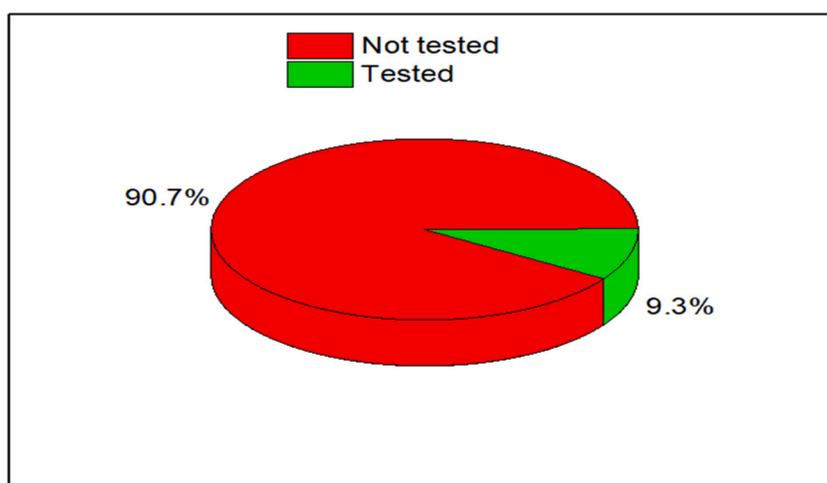


Fig. 20. Summary from Tables 1 and 2, the percentage of chloride ion tests conducted on the reviewed literatures.

- The review observed, as natural SCMs can more replace cement content to get the optimum strength of cement composite materials. This is an indication as natural SCMs can significantly reduce energy consumption and environmental pollution coming due to cement production by replacing cement more than artificial SCMs.
- Employing most of the artificial and natural SCMs significantly improve durability, especially reduce water absorption and improve acidic resistance compared to conventional cement composite materials. This is mainly due to most SCMs are fine and have a large surface area than cement particles which can fill the pores and reduce penetration of water and acids.
- Addition of SCMs in cement composite makes a dense microstructure of cement matrix. That is because, many of SCMs have micro-filling ability and actively react with free lime in cement to form extra C-S-H. This C-S-H potentially can participate in the improvement of the microstructural appearance and durability of the cement matrix. Hence, most of the reviewed literatures indicated that incorporation of SCMs in cement composite significantly improves durability, however silica fume and volcanic ash have seen very limited studies on water absorption and acidic attack resistance of blended cement composite. So the authors recommend future researchers focus on the effect of silica fume and volcanic ash on the durability of cementitious materials.

Generally, from most literatures have seen positive effects on the addition of artificial and natural SCMs in cement composite due to active pozzolanic reactions between reactive silica/alumina from SCMs and calcium hydroxide from cement that forms secondary calcium silicate hydrate (C-S-H) or calcium aluminate silicate hydrates (C-A-S-H) which can play a great role in the improvement of physical, mechanical, durability, and microstructural properties of cement composite materials.

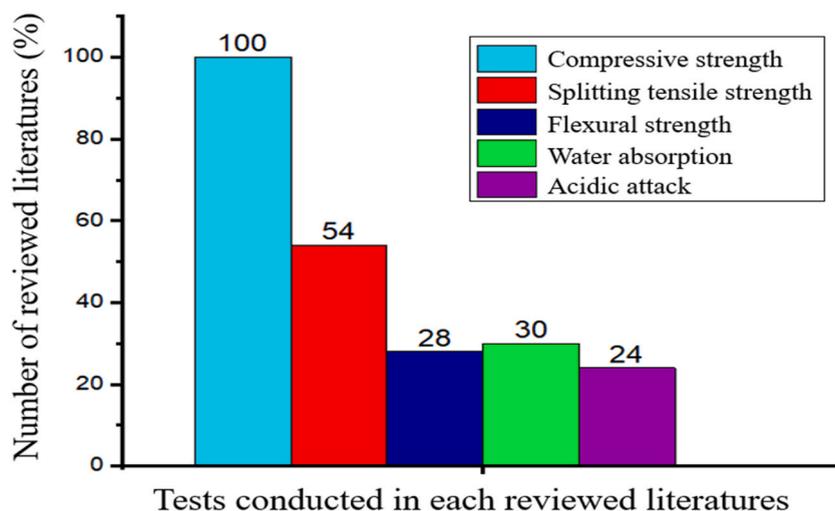


Fig. 21. Summary from Tables 3–9, the percentage of different tests conducted in each reviewed literatures.

5. Future perspectives

The most crucial consideration has been seen is that many of the reviewed literatures for the chemical composition of silica fume indicated extremely high silica content which is more than 90%, though ASTM C618 [86] recommends addition for the values of sulfur dioxide (SiO_2), Aluminum oxide (Al_2O_3), and Iron oxide (Fe_2O_3) greater than 70%. So it is beneficial to isolately investigate the effect of sulfur dioxide in silica fume can possess on the mechanical, physical, and microstructural properties of cementitious materials. Also, deep investigation is necessary on the durability of silica fume composite cement materials since its observed very limited studies on water absorption and acidic attacks due to silica fume.

Generally, it is observed, as there are limited studies on volcanic ash employment on cement composite especially on researching its effect on flexural strength, split tensile strength, and microstructure of construction materials, it is crucial to more analyze the effects of volcanic ash on mechanical properties, durability and microstructural change on cement composite.

6. Gap analysis of results and future recommendation

Although, all the reviewed literatures are important and solved the gap of knowledge concerning artificial and natural SCMs, but the following needs more considerations:

1. As presented in Fig. 20, more than 90% of reviewed literatures did not test the amount of chloride ions that exist in each of the sampled SCMs, however, knowing its content in every sampled SCMs is very crucial since can cause corrosion of steel bar in cement composite materials.
2. As shown in Fig. 21, all and more than half of the reviewed literatures conducted compressive and split tensile strength tests respectively. However, it is observed that more than 70% of the reviewed literatures did not conduct flexural strength, water absorption, and acidic attack tests. Especially, water absorption and acidic attack are very important indicators of the durability of cement composite materials employed with SCMs. In general, the review has seen very limited indicators of durability tests of cement composite materials like shrinkage, ultrasonic velocity, and toughness tests, hence the authors recommend the future studies focus more on the effect of artificial and natural SCMs on the durability of cement composite materials.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

Data included in article/supp. Material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- [1] K.L. Scrivener, V.M. John, E.M. Gartner, Eco-efficient cements: potential economically viable solutions for a low-CO₂ cement-based materials industry, *Cement Concr. Res.* 114 (2018) 2–26, <https://doi.org/10.1016/j.cemconres.2018.03.015>.
- [2] S. Nuhu, S. Ladan, A. Umar Muhammad, Effects and control of chemical composition of clinker for cement production, *Int. J. Control Sci. Eng.* 2020 (2020) 16–21, <https://doi.org/10.5923/j.control.20201001.03>.
- [3] A. Sharma, Glass powder – a partial replacement for cement, *Int. J. Core Eng. Manag.* 1 (2015) 86–93.
- [4] J.W. Bang, G.G. Prabhu, Y. Il Jang, Y.Y. Kim, Development of ecoefficient engineered cementitious composites using supplementary cementitious materials as a binder and bottom ash aggregate as fine aggregate, *Int. J. Polym. Sci.* 2015 (2015), <https://doi.org/10.1155/2015/681051>. (Research).
- [5] M. Jafari Nadoushan, A.A. Ramezani-pour, The effect of type and concentration of activators on flowability and compressive strength of natural pozzolan and slag-based geopolymers, *Construct. Build. Mater.* 111 (2016) 337–347, <https://doi.org/10.1016/j.conbuildmat.2016.02.086>.
- [6] N. Cobirzan, A.-A. Balog, E. Mosonyi, Investigation of the natural pozzolans for usage in cement industry, *Procedia Technol* 19 (2015) 506–511, <https://doi.org/10.1016/j.protcy.2015.02.072>.
- [7] A. Lotfy, O. Karahan, E. Ozbay, K.M.A. Hossain, M. Lachemi, Effect of kaolin waste content on the properties of normal-weight concretes, *Construct. Build. Mater.* 83 (2015) 102–107, <https://doi.org/10.1016/j.conbuildmat.2015.03.002>.
- [8] A. Kaur, V.P.S. Sran, Use of metakaolin as pozzolanic material and partial replacement with cement in concrete (M30), *Asian Rev. Mech. Eng.* 5 (2016) 9–13. www.trp.org.
- [9] G.L. Golewski, Fracture performance of cementitious composites based on quaternary blended cements, *Materials* (2022), <https://doi.org/10.3390/ma15176023>.
- [10] S.H. Channa, S.A. Mangi, N. Bheel, F.A. Soomro, S.H. Khahro, Short-term analysis on the combined use of sugarcane bagasse ash and rice husk ash as supplementary cementitious material in concrete production, *Environ. Sci. Pollut. Res.* (2022) 3555–3564, <https://doi.org/10.1007/s11356-021-15877-0>.
- [11] T. Milović, S. Supić, M. Malešev, V. Radonjanin, The effects of natural zeolite as fly ash alternative on frost resistance and shrinkage of blended cement mortars, *Sustain.* 14 (2022), <https://doi.org/10.3390/su14052736>.
- [12] H.M. Hamada, B. Skariah, F.M. Yahaya, K. Muthusamy, J. Yang, J.A. Abdalla, R.A. Hawileh, M. Pascal, Sustainable use of palm oil fuel ash as a supplementary cementitious material : a comprehensive review, *J. Build. Eng.* 40 (2021), 102286, <https://doi.org/10.1016/j.job.2021.102286>.
- [13] A.I. Nicoara, A.E. Stoica, M. Vrabec, N.Š. Rogan, S. Sturm, C. Ow-yang, M.A. Gulgun, Z.B. Bundur, I. Ciuca, B.S. Vasile, End-of-Life materials used as supplementary cementitious materials in the concrete industry, *Materials* (2020) 1–20, <https://doi.org/10.3390/ma13081954>.
- [14] S.V.G. Barbara, L. Anya, B. Wu, B. Huet, C. Andrade, C. Thiel, E. Gruyaert, H. Vanoutrive, I.F. Sae, J.L. Provis, K.T. Kosmas, S. Maciej, Z. Natalia, M. Geiker, G. Gluth, R.D. Hooton, Understanding the carbonation of concrete with supplementary cementitious materials : a critical review by RILEM TC 281-CCC, *Mater. Struct.* (2020), 0123456789, <https://doi.org/10.1617/s11527-020-01558-w>.
- [15] K. Mohamed, R. Mateus, L. Bragança, Comparative sustainability assessment of binary blended concretes using supplementary cementitious materials (SCMs) and ordinary portland cement (OPC), *J. Clean. Prod.* 220 (2019) 445–459, <https://doi.org/10.1016/j.jclepro.2019.02.010>.
- [16] L. Renato, A. Michael, F. Pelisser, Sustainable Materials and Technologies Effectiveness of ceramic tile polishing residues as supplementary cementitious materials for cement mortars, *Sustain. Mater. Technol. Eff.* 4 (2015) 30–35, <https://doi.org/10.1016/j.susmat.2015.05.001>.
- [17] S. Kumar, A review on wider application of supplementary cementitious materials on the development of high-performance concrete, *Int. J. Civ. Eng. Technol.* 9 (2018) 187–204. <http://iaeme.com/Home/issue/IJCIET?Volume=9&Issue=8> ISSN.
- [18] Y. Zhao, J. Qiu, J. Xing, X. Sun, Recycling of quarry dust for supplementary cementitious materials in low carbon cement, *Construct. Build. Mater.* 237 (2020), 117608, <https://doi.org/10.1016/j.conbuildmat.2019.117608>.
- [19] S. Alper, B.A. Tayeh, G. Calis, Experimental and modelling study of mixture design optimisation of glass fibre-reinforced concrete with combined utilisation of Taguchi and Extreme Vertices Design Techniques, *Integr. Med. Res.* 9 (2020) 2093–2106, <https://doi.org/10.1016/j.jmr.2020.02.083>.
- [20] S.C. Taylor-Lange, E.L. Lamon, K.A. Riding, M.C.G. Juenger, Calcined kaolin-bentonite clay blends as supplementary cementitious materials, *Appl. Clay Sci.* 108 (2015) 84–93, <https://doi.org/10.1016/j.clay.2015.01.025>.
- [21] Y. Zhang, J. Zhang, W. Luo, J. Wang, J. Shi, H. Zhuang, Y. Wang, Effect of compressive strength and chloride diffusion on life cycle CO₂ assessment of concrete containing supplementary cementitious materials, *J. Clean. Prod.* 218 (2019) 450–458, <https://doi.org/10.1016/j.jclepro.2019.01.335>.
- [22] A. Arrigoni, D.K. Panesar, M. Duhamel, T. Opher, S. Saxe, I.D. Posen, H.L. MacLean, Life cycle greenhouse gas emissions of concrete containing supplementary cementitious materials: cut-off vs. substitution, *J. Clean. Prod.* 263 (2020), 121465, <https://doi.org/10.1016/j.jclepro.2020.121465>.
- [23] Z. Tafheem, S. Khusru, S. Nasrin, Environmental impact of green concrete in practice, *Int. Conf. Mech. Eng. Renew. Energy* 2011 (2011) 7. https://www.researchgate.net/publication/280445221_Environmental_Impact_of_Green_Concrete_in_Practice.
- [24] S. Cheng, Z. Shui, T. Sun, R. Yu, G. Zhang, Durability and microstructure of coral sand concrete incorporating supplementary cementitious materials, *Construct. Build. Mater.* 171 (2018) 44–53, <https://doi.org/10.1016/j.conbuildmat.2018.03.082>.
- [25] L. Hu, Z. He, S. Zhang, Sustainable use of rice husk ash in cement-based materials: environmental evaluation and performance improvement, *J. Clean. Prod.* 264 (2020), 121744, <https://doi.org/10.1016/j.jclepro.2020.121744>.
- [26] M.U. Hossain, C.S. Poon, Y.H. Dong, D. Xuan, Evaluation of environmental impact distribution methods for supplementary cementitious materials, *Renew. Sustain. Energy Rev.* 82 (2018) 597–608, <https://doi.org/10.1016/j.rser.2017.09.048>.
- [27] S. Ruan, C. Unluer, Influence of supplementary cementitious materials on the performance and environmental impacts of reactive magnesia cement concrete, *J. Clean. Prod.* 159 (2017) 62–73, <https://doi.org/10.1016/j.jclepro.2017.05.044>.
- [28] W. Deboucha, M.N. Oudjit, A. Bouzid, L. Belagraa, Effect of incorporating blast furnace slag and natural pozzolana on compressive strength and capillary water absorption of concrete, *Procedia Eng.* 108 (2015) 254–261, <https://doi.org/10.1016/j.proeng.2015.06.145>.
- [29] M.N.N. Khan, M. Jamil, M.R. Karim, M.F.M. Zain, A.B.M.A. Kaish, Filler effect of pozzolanic materials on the strength and microstructure development of mortar, *KSCSE J. Civ. Eng.* 21 (2017) 274–284, <https://doi.org/10.1007/s12205-016-0737-5>.
- [30] J. Macfarlane, A review on use of metakaolin in concrete, *Eng. Sci. Technol. An Int. J.* 3 (2013) 2250–3498.
- [31] P. Ashish, C. Srinivasarao, Influence of bentonite as partial replacement of cement in basalt fiber concrete, in: *IOP Conf. Ser. Mater. Sci. Eng.*, IOP Publishing, 2021, 012015, <https://doi.org/10.1088/1757-899x/1185/1/012015>.
- [32] S. Park, S. Wu, Z. Liu, S. Pyo, The role of supplementary cementitious materials (SCMs) in ultra high performance concrete (UHPC): a review, *Mater. MDPI.* (2021) 1–24, <https://doi.org/10.3390/ma14061472>.
- [33] R. Jaskulski, J. Daria, Calcined Clay as Supplementary Cementitious Material, *Mater. MDPI.*, 2020.
- [34] A. Alujas, R. Fernández, R. Quintana, K.L. Scrivener, F. Martirena, Applied Clay Science Pozzolanic reactivity of low grade kaolinitic clays : in fl fluence of calcination temperature and impact of calcination products on OPC hydration, *Appl. Clay Sci.* (2015) 1–8, <https://doi.org/10.1016/j.clay.2015.01.028>.
- [35] J.L. Costafreda, D.A. Mart, L. Presa, Effects of a natural mordenite as pozzolan material in the evolution of mortar settings, *Mater. MDPI.* (2021) 1–22, <https://doi.org/10.3390/ma14185343>.

- [36] M. Firdous, B. Singh, Supplementary cementitious materials in concrete and associated structural and environmental benefits : a review Supplementary cementitious materials in concrete and associated structural and environmental benefits : a review, IOP Conf. Ser. Earth Environ. Sci. (2021), <https://doi.org/10.1088/1755-1315/889/1/012077>.
- [37] B. Pacewska, I. Wilińska, Usage of supplementary cementitious materials : advantages and limitations, J. Therm. Anal. Calorim. 142 (2020) 371–393, <https://doi.org/10.1007/s10973-020-09907-1>.
- [38] P. Aïtcin, Supplementary Cementitious Materials and Blended Cements, Elsevier Ltd, 2016, <https://doi.org/10.1016/B978-0-08-100693-1.00004-7>.
- [39] S.A. Abdul-Wahab, E.M. Hassan, K.S. Al-Jabri, K. Yetilmezsoy, Application of zeolite/kaolin combination for replacement of partial cement clinker to manufacture environmentally sustainable cement in Oman, Environ. Eng. Res. 24 (2019) 246–253, <https://doi.org/10.4491/EEER.2018.047>.
- [40] K. Mermerdaş, M. Gesoğlu, E. Güneyisi, T. Özturan, Strength development of concretes incorporated with metakaolin and different types of calcined kaolins, Construct. Build. Mater. 37 (2012) 766–774, <https://doi.org/10.1016/j.conbuildmat.2012.07.077>.
- [41] B.A. Tayeh, Effects of marble , timber , and glass powder as partial replacements for cement, J. Civ. Eng. Constr. 2 (2018) 63–71.
- [42] S. Ferreiro, M.M.C. Canut, J. Lund, D. Herfort, Influence of fineness of raw clay and calcination temperature on the performance of calcined clay-limestone blended cements, Appl. Clay Sci. 169 (2019) 81–90, <https://doi.org/10.1016/j.clay.2018.12.021>.
- [43] S. Salamatpoor, Y. Jafarian, A. Hajjani, Physical and mechanical properties of sand stabilized by cement and natural zeolite, Eur. Phys. J. Plus. 133 (2018), <https://doi.org/10.1140/epjp/i2018-12016-0>.
- [44] M.I. Khan, A.M. Alhozaimey, Properties of natural pozzolan and its potential utilization in environmental friendly concrete, Can. J. Civ. Eng. 38 (2011) 71–78, <https://doi.org/10.1139/L10-112>.
- [45] A.A. Al-hamood, Iraqi bentonite as a natural pozzolan for sustainable concrete, Res. Sq. (2021) 1–23, <https://doi.org/10.21203/rs.3.rs-437439/v1> License.
- [46] S.M.Q. Taklymi, O. Rezaifar, M. Gholhaki, Investigating the properties of bentonite and kaolin modified concrete as a partial substitute to cement, SN Appl. Sci. 2 (2020) 1–14, <https://doi.org/10.1007/s42452-020-03380-z>.
- [47] A. Trümer, H.M. Ludwig, M. Schellhorn, R. Diedel, Effect of a calcined Westerwald bentonite as supplementary cementitious material on the long-term performance of concrete, Appl. Clay Sci. 168 (2019) 36–42, <https://doi.org/10.1016/j.clay.2018.10.015>.
- [48] M. Sriwattanapong Photisan, Influence of the calcination thickness of kaolin on strength development of mortars, Knowl. Innov. Eng. Sci. Technol. (2018) 1–11, <https://doi.org/10.33422/4kiconf.2018.12.22>.
- [49] M.A. Elahi, C.R. Shearer, A. Naser, R. Reza, A. Kumer, N. Newaz, M. Hossain, P. Kumar, Improving the sulfate attack resistance of concrete by using supplementary cementitious materials (SCMs): a review, Construct. Build. Mater. 281 (2021), 122628, <https://doi.org/10.1016/j.conbuildmat.2021.122628>.
- [50] A.N. Mohammed, A. Megat, M. Johari, A.M. Zeyad, B.A. Tayeh, M.O. Yusuf, D.C.L. Teo, A. Mannan, J. V Kuriam, C. Rice, H. Ash, H. Bin Mahmud, M. Dnkdu, A. Malik, R.A. Kahar, M.G.D.X.L. Dliq, A.N. Mohammed, M. Azmi, M. Johari, A.M. Zeyad, B.A. Tayeh, M.O. Yusuf, Improving the engineering and fluid transport properties of ultra-high strength concrete utilizing ultrafine palm oil fuel ash, J. Adv. Concr. Technol. 12 (2014) 127–137, <https://doi.org/10.3151/jact.12.127>.
- [51] H. Hamada, B. Tayeh, F. Yahaya, K. Muthusamy, Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete, Construct. Build. Mater. 261 (2020), 119790, <https://doi.org/10.1016/j.conbuildmat.2020.119790>.
- [52] D.K. Panesar, R. Zhang, Performance comparison of cement replacing materials in concrete : limestone fillers and supplementary cementing materials – a review, Construct. Build. Mater. 251 (2020), 118866, <https://doi.org/10.1016/j.conbuildmat.2020.118866>.
- [53] K. Kalinowska-wichrowska, M. Kosior-kazberuk, The properties of composites with recycled cement mortar used as a supplementary cementitious, Material, Mater. MDPI. (2020), <https://doi.org/10.3390/ma13010064>.
- [54] N. Lovecchio, F. Shaikh, M. Rosano, R. Ceravolo, W. Biswas, Agricultural solid waste as source of supplementary cementitious materials in developing countries, Environ. Sci. 7 (2020) 13–30, <https://doi.org/10.3934/environsci.2020002>.
- [55] L. Gabriel, G. De Godoy, A. Bernardo, M. Regina, E. Bastos, S. Da, J. José, D.O. Andrade, Valorization of water treatment sludge waste by application as supplementary cementitious material, Construct. Build. Mater. 223 (2019) 939–950, <https://doi.org/10.1016/j.conbuildmat.2019.07.333>.
- [56] S. Gupta, S. Chaudhary, State of the art review on Supplementary Cementitious Materials in India e I : an overview of legal perspective , governing organizations , and development patterns, J. Clean. Prod. 261 (2020), 121203, <https://doi.org/10.1016/j.jclepro.2020.121203>.
- [57] T.P. Madhavi, V. Sampathkumar, P. Gunasekaran, Partial replacement of cement and fine aggregate by using fly ash and glass aggregate, Int. J. Res. Eng. Technol. 2 (2013) 351–355, <https://doi.org/10.15623/ijret.2013.0213066>.
- [58] S.W. Dhengare, S.P. Raut, N. V Bandwal, A. Khandan, Investigation into utilization of sugarcane bagasse ash as supplementary cementitious material in concrete, Int. J. Emerg. Eng. Res. Technol. 3 (2015) 109–116.
- [59] S. Dhengare, S. Amrodiya, M. Shelote, A. Asati, N. Bandwal, A. Khandan, R. Jichkar, Utilization of sugarcane bagasse ash as a supplementary cementitious material in concrete and mortar - a review, Natl. J. Civ. Eng. Technol. (2015) 94–106, [iaeme: www.iaeme.com/IJCIET.asp](http://www.iaeme.com/IJCIET.asp).
- [60] W. Tangchirapat, C. Jaturapitakkul, P. Chindaprasirt, Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete, Construct. Build. Mater. 23 (2009) 2641–2646, <https://doi.org/10.1016/j.conbuildmat.2009.01.008>.
- [61] A.-M. Shakir, I. Amer, N. Zeinab, The effect of nano metakaolin material on some properties of concrete, Diyala J. Eng. Sci. 6 (2013) 50–61, <https://doi.org/10.24237/djes.2013.06105>.
- [62] I.U. Haq*, A. Elahi, S.A.Q. Shah, M.A. Ghaffar, Fresh, mechanical and durability properties of polypropylene concrete containing bentonite & silica fume, in: 3rd Conf. Sustain. Civ. Eng., 2022.
- [63] C.D. Isberto, K.L. Labra, J.M.B. Landicho, R. De Jesus, Optimized preparation of rice HUSK ash (rha) as a supplementary cementitious material, Int. J. GEOMATE 16 (2019) 56–61, <https://doi.org/10.21660/2019.57.4628>.
- [64] O.G. Mark, A.N. Ede, O. Olofinnade, G. Bamigboye, C. Okeke, S.O. Oyebeisi, C. Arum, Influence of some selected supplementary cementitious materials on workability and compressive strength of concrete – a review influence of some selected supplementary cementitious materials on workability and compressive strength of concrete – a review, in: 1st Int. Conf. Sustain. Infrastructural Dev., 2019, <https://doi.org/10.1088/1757-899X/640/1/012071>.
- [65] M.C.G. Juenger, R. Snellings, S.A. Bernal, Cement and Concrete Research Supplementary cementitious materials : new sources , characterization , and performance insights, Cement Concr. Res. 122 (2019) 257–273, <https://doi.org/10.1016/j.cemconres.2019.05.008>.
- [66] A.T. Bakera, M.G. Alexander, Use of metakaolin as a supplementary cementitious material in concrete , with a focus on durability properties, RILEM Tech. Lett. (2019), <https://doi.org/10.21809/rilemtechlett.2019.94> Use.
- [67] N. Altwair, S. Kabir, Palm oil fuel ash (POFA): an environmentally-friendly cementitious material for concrete production, in: Int. Conf. Mater. Sci. 64th RILEM Annu. Week Aachen - MATSCI Palm, 2015.
- [68] Y. Senhadji, G. Escadeillas, H. Khelafi, M. Mouli, Y. Senhadji, G. Escadeillas, H. Khelafi, M. Mouli, Evaluation of natural pozzolan for use as supplementary cementitious material, Eur. J. Environ. Civ. Eng. 8189 (2012), <https://doi.org/10.1080/19648189.2012.667692>.
- [69] B.J. Mohr, J.J. Biernacki, K.E. Kurtis, Supplementary cementitious materials for mitigating degradation of kraft pulp fiber-cement composites, Cement Concr. Res. 37 (2007) 1531–1543, <https://doi.org/10.1016/j.cemconres.2007.08.001>.
- [70] R. Pierkes, S.E. Schulze, J. Rickert, Optimization of cements with calcined clays as supplementary cementitious materials, in: Calcined Clays Sustain. Concr., 2015, <https://doi.org/10.1007/978-94-017-9939-3>.
- [71] G.L. Golewski, An extensive investigations on fracture parameters of concretes based on quaternary binders (QBC) by means of DIC technique, Construct. Build. Mater. 351 (2022), 128823, <https://doi.org/10.1016/j.conbuildmat.2022.128823>.
- [72] N. Hilal, T. Kh. M. Ali, B.A. Tayeh, Properties of environmental concrete that contains crushed walnut shell as partial replacement for aggregates, Arabian J. Geosci. (2020), <https://doi.org/10.1007/s12517-020-05733-9>.
- [73] S. Sakir, S.N. Raman, A.B.M.A. Kaish, A.A. Mutalib, Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction, MDPI-Sustainability (2020), <https://doi.org/10.3390/su12093888>.

- [74] L.N. Assi, A. Alsalmán, Y.A.J. Al-Hamadani, R. Kareem, H.M.A. Al, Khuzaie, observations of supplementary cementitious materials effects on the performance of concrete foundation observations of supplementary cementitious materials effects on the performance of concrete foundation, Second Int. Conf. Geotech. Eng. (2021), <https://doi.org/10.1088/1755-1315/856/1/012020>.
- [75] A.S. Faried, S.A. Mostafa, B.A. Tayeh, T.A. Tawfik, Mechanical and durability properties of ultra-high performance concrete incorporated with various nano waste materials under different curing conditions, J. Build. Eng. 43 (2021), 102569, <https://doi.org/10.1016/j.jobte.2021.102569>.
- [76] H. Ivashchyshyn, M. Sanysky, T. Kropyvnytska, B. Rusyn, LOW-EMISSION component cements with a high SUPPLEMENTARY materials, E. Eur. J. Enterprise Technol. (2019) 39–47, <https://doi.org/10.15587/1729-4061.2019.175472>.
- [77] B.A. Tayeh, D.M. Al, A.S. Aadi, I. Almehsal, Sulphate resistance of cement mortar contains glass powder, J. King Saud Univ. - Eng. Sci. 32 (2020) 495–500, <https://doi.org/10.1016/j.jksues.2019.07.002>.
- [78] S. Raju, J. Rathinam, B. Dharmar, S. Rekha, S. Avudaiappan, M. Amran, K.I. Usanova, R. Fediuk, P. Guindos, R.V. Ramamoorthy, Cyclically loaded copper slag admixed reinforced concrete beams with cement partially replaced with fly ash, Materials 15 (2022) 1–24, <https://doi.org/10.3390/ma15093101>.
- [79] G.L. Golewski, Comparative measurements of fracture toughness combined with visual analysis of cracks propagation using the DIC technique of concretes based on cement matrix with a highly diversified composition, Theor. Appl. Fract. Mech. (2022), <https://doi.org/10.1016/j.tafmec.2022.103553>.
- [80] P. V. Madhuri, B.K. Rao, A. Chaitanya, Improved performance of concrete incorporated with natural zeolite powder as supplementary cementitious material, Mater. Today Proc. (2021), <https://doi.org/10.1016/j.matpr.2021.06.089>.
- [81] B.A. Tayeh, R. Alyousef, H. Alabduljabbar, A. Alaskar, Recycling of rice husk waste for a sustainable concrete : a critical review, J. Clean. Prod. 312 (2021), 127734, <https://doi.org/10.1016/j.jclepro.2021.127734>.
- [82] S. Ramanathan, M. Croly, P. Suraneni, Comparison of the effects that supplementary cementitious materials replacement levels have on cementitious paste properties, Cem. Concr. Compos. 112 (2020), 103678, <https://doi.org/10.1016/j.cemconcomp.2020.103678>.
- [83] K.M. Mane, D.K. Kulkarni, K.B. Prakash, Near-surface and chloride permeability of concrete using pozzolanic materials and manufactured sand as partial replacement of fine aggregate, Iran. J. Sci. Technol. - Trans. Civ. Eng. 45 (2021) 1427–1439, <https://doi.org/10.1007/s40996-020-00543-1>.
- [84] G.L. Golewski, The role of pozzolanic activity of siliceous fly ash in the formation of the structure of sustainable cementitious composites, Sustain. Chem. (2022) 520–534, <https://doi.org/10.3390/suschem3040032>.
- [85] J. Setina, A. Gabrene, I. Juhnveica, Effect of pozzolanic additives on structure and chemical durability of concrete, Procedia Eng. 57 (2013) 1005–1012, <https://doi.org/10.1016/j.proeng.2013.04.127>.
- [86] A. C618, Standard specification for coal fly ash and raw or calcined natural pozzolana for use in concrete, in: ASTM International, West Conshohocken, PA, 2012, ASTM Stand., 2010, pp. 3–6, <https://doi.org/10.1520/C0618>.
- [87] A.C. Avdar, S. Yetgin, Availability of tuffs from northeast of Turkey as natural pozzolan on cement , some chemical and mechanical relationships, Construct. Build. Mater. J. 21 (2007) 2066–2071, <https://doi.org/10.1016/j.conbuildmat.2006.05.034>.
- [88] A.O. Arinkoola, S.O. Alagbe, K.K. Salam, B.M. Ajagbe, I.O. Akinwole, Assessment of Nigerian calcium bentonite as cement replacement for shallow depth oil well cementing operation, Niger. J. Technol. Dev. 19 (2022) 250–259, <https://doi.org/10.4314/njtd.v19i3.7>.
- [89] A. El Refaey, Effect of calcination and Ca-modified on bentonite and zeolite, with respect to phosphorus removal from aqueous solution, Egypt, J. Soil Sci. (2022), <https://doi.org/10.21608/ejss.2022.108515.1482>.
- [90] L. Keke, L. Yong, X. Liuliu, Z. Junjie, L. Kangning, F. Dingqiang, Rheological characteristics of Ultra-High performance concrete (UHPC) incorporating bentonite, Construct. Build. Mater. 349 (2022), 128793, <https://doi.org/10.1016/j.conbuildmat.2022.128793>.
- [91] K. Nakarai, M. Shibata, H. Sakamoto, H. Owada, G. Kosakowski, Calcite precipitation at cement – bentonite interface . Part 1 : effect of carbonate admixture in bentonite, J. Adv. Concr. Technol. 19 (2021) 433–446, <https://doi.org/10.3151/jact.19.433>.
- [92] N. Mesboua, K. Benyounes, S. Kennouche, Y. Ammar, A. Benmounah, H. Kemer, Calcinated bentonite as supplementary cementitious materials in cement-based mortar, J. Appl. Eng. Sci. 11 (2021) 23–32, <https://doi.org/10.2478/jaes-2021-0004>.
- [93] Z. Zhao, M. Chen, X. Zhong, Y. Huang, L. Yang, P. Zhao, S. Wang, L. Lu, X. Cheng, Effects of bentonite , diatomite and metakaolin on the rheological behavior of 3D printed magnesium potassium phosphate cement composites, Addit. Manuf. 46 (2021), 102184, <https://doi.org/10.1016/j.addma.2021.102184>.
- [94] R.M. Waqas, F. Butt, A. Danish, M. Alqurashi, M.A. Mosaberpanah, B. Masood, E.E. Hussein, Influence of bentonite on mechanical and durability properties of high-calcium fly ash geopolymer concrete with natural and recycled aggregates, Materials-MDPI 14 (2021), <https://doi.org/10.3390/ma14247790>.
- [95] S. Adjei, S. Elkhatatny, P. Sarmah, A. Mohsen, Evaluation of calcined Saudi calcium bentonite as cement replacement in low-density oil-well cement system, J. Pet. Sci. Eng. 205 (2021), 108901, <https://doi.org/10.1016/j.petrol.2021.108901>.
- [96] B. Masood, A. Elahi, S. Barbhuiya, B. Ali, Mechanical and durability performance of recycled aggregate concrete incorporating low calcium bentonite, Construct. Build. Mater. 237 (2020), 117760, <https://doi.org/10.1016/j.conbuildmat.2019.117760>.
- [97] M.Z. Ahad, M. Ashraf, R. Kumar, Thermal, physico-chemical, and mechanical behaviour of mass concrete with hybrid blends of bentonite and fly ash, Materials-MDPI (2018), <https://doi.org/10.3390/ma12010060>.
- [98] Y. Xie, J. Li, Z. Lu, J. Jiang, Y. Niu, Effects of bentonite slurry on air-void structure and properties of foamed concrete, Construct. Build. Mater. 179 (2018) 207–219, <https://doi.org/10.1016/j.conbuildmat.2018.05.226>.
- [99] G.F.M. Mouanda, S.O. Abuodha, J.N. Thuo, Gum Arabic as an admixture in modified concrete mixed with calcined kaolin, Civ. Eng. J. 8 (2022) 985–998, <https://doi.org/10.28991/CEJ-2022-08-05-010>.
- [100] H. Du, S.D. Pang, High-performance concrete incorporating calcined kaolin clay and limestone as cement substitute, Construct. Build. Mater. 264 (2020), 120152, <https://doi.org/10.1016/j.conbuildmat.2020.120152>.
- [101] G. Asadolahfardi, P. MohsenZadeh, S.F. Saghravani, N. mohamadzadeh, The effects of using metakaolin and micro-nanobubble water on concrete properties, J. Build. Eng. 25 (2019), 100781, <https://doi.org/10.1016/j.jobte.2019.100781>.
- [102] A. Saand, M.A. Keerio, D.K. Bangwar, Effect of soorh metakaolin on concrete compressive strength and durability, Eng. Technol. Appl. Sci. Res. 7 (2017) 2210–2214, <https://doi.org/10.48084/etasr.1494>.
- [103] H. El-Diadamony, A.A. Amer, T.M. Sokkary, S. El-Hoseny, Hydration and characteristics of metakaolin pozzolanic cement pastes, HBRC J 14 (2016) 150–158, <https://doi.org/10.1016/j.hbrj.2015.05.005>.
- [104] A. Soury, H. Kazemi-Kamyab, R. Snellings, R. Naghizadeh, F. Golestani-Fard, K. Scrivener, Pozzolanic activity of mechanochemically and thermally activated kaolins in cement, Cement Concr. Res. 77 (2015) 47–59, <https://doi.org/10.1016/j.cemconres.2015.04.017>.
- [105] Z. Shi, Z. Shui, Q. Li, H. Geng, Combined effect of metakaolin and sea water on performance and microstructures of concrete, Construct. Build. Mater. 74 (2015) 57–64, <https://doi.org/10.1016/j.conbuildmat.2014.10.023>.
- [106] N. Shafiq, M.F. Nuruddin, S.U. Khan, T. Ayub, Calcined kaolin as cement replacing material and its use in high strength concrete, Construct. Build. Mater. 81 (2015) 313–323, <https://doi.org/10.1016/j.conbuildmat.2015.02.050>.
- [107] A.M. Rashad, A preliminary study on the effect of fine aggregate replacement with metakaolin on strength and abrasion resistance of concrete, Construct. Build. Mater. 44 (2013) 487–495, <https://doi.org/10.1016/j.conbuildmat.2013.03.038>.
- [108] D. Zhao, R. Khoshnazar, Microstructure of cement paste incorporating high volume of low-grade metakaolin, Cem. Concr. Compos. 106 (2020), 103453, <https://doi.org/10.1016/j.cemconcomp.2019.103453>.
- [109] F. Zunino, E. Boehm-Courjault, K. Scrivener, The impact of calcite impurities in clays containing kaolinite on their reactivity in cement after calcination, Mater. Struct. Constr. 53 (2020), <https://doi.org/10.1617/s11527-020-01478-9>.
- [110] M. Narmatha, D.T. Felikkala, Meta kaolin –the best material for replacement of cement in concrete, IOSR J. Mech. Civ. Eng. 13 (2016) 66–71, <https://doi.org/10.9790/1684-1304016671>.
- [111] A.M. Zeyad, A. Almalki, Role of particle size of natural pozzolanic materials of volcanic pumice: flow properties, strength, and permeability, Arabian J. Geosci. 14 (2021), <https://doi.org/10.1007/s12517-020-06443-y>.
- [112] M. Ibrahim, M. Azmi, M. Johari, S.R. Hussaini, M.K. Rahman, M. Masleuddin, Influence of pore structure on the properties of green concrete derived from natural pozzolan and nanosilica, J. Sustain. Cem. Mater. 0 (2020) 1–25, <https://doi.org/10.1080/21650373.2020.1715901>.

- [113] V.T. Pham, P. Meng, P. Trinh, Y. Ogawa, K. Kawai, Effects of Shirasu natural pozzolan and limestone powder on the strength and aggressive chemical resistance of concrete, *Construct. Build. Mater.* 239 (2020), 117679, <https://doi.org/10.1016/j.conbuildmat.2019.117679>.
- [114] F. Dif, T.H. Douara, R. Zaitri, M. Mouli, Effects of combined natural volcanic powders on the thermo-physical and mechanical properties of structural eco-concrete, *J. Build. Eng.* 32 (2020), 101835, <https://doi.org/10.1016/j.jobbe.2020.101835>.
- [115] K. Celik, R. Hay, C.W. Hargis, J. Moon, Effect of volcanic ash pozzolan or limestone replacement on hydration of Portland cement, *Construct. Build. Mater.* 197 (2019) 803–812, <https://doi.org/10.1016/j.conbuildmat.2018.11.193>.
- [116] A.M. Zeyad, B.A. Tayeh, M.O. Yusuf, Strength and transport characteristics of volcanic pumice powder based high strength concrete, *Construct. Build. Mater.* 216 (2019) 314–324, <https://doi.org/10.1016/j.conbuildmat.2019.05.026>.
- [117] M. Elbar, Y. Senhadji, A.S. Benosman, H. Khelafi, M. Mouli, Effect of thermo-activation on mechanical strengths and chlorides permeability in pozzolanic materials, *Case Stud. Constr. Mater.* 8 (2018) 459–468, <https://doi.org/10.1016/j.cscm.2018.04.001>.
- [118] W. Wilson, J.M. Rivera-Torres, L. Sorelli, A. Durán-Herrera, A. Tagnit-Hamou, The micromechanical signature of high-volume natural pozzolan concrete by combined statistical nanoindentation and SEM-EDS analyses, *Cem. Concr. Res.* 91 (2017) 1–12, <https://doi.org/10.1016/j.cemconres.2016.10.004>.
- [119] I. Hammoud, A. Meziab, Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil, *J. Rock Mech. Geotech. Eng.* (2016) 1–12, <https://doi.org/10.1016/j.jrmge.2016.04.002>.
- [120] A. Merida, F. Kharchi, Pozzolan concrete durability on sulphate attack, *Procedia Eng.* 114 (2015) 832–837, <https://doi.org/10.1016/j.proeng.2015.08.035>.
- [121] A.M. Zeyad, A. Husain, B.A. Tayeh, Durability and strength characteristics of high-strength concrete incorporated with volcanic pumice powder and polypropylene fibers, *Integr. Med. Res.* (2019) 1–13, <https://doi.org/10.1016/j.jmrt.2019.11.021>.
- [122] M. Abdi Moghadam, R.A. Izadifard, Experimental investigation on the effect of silica fume and zeolite on mechanical and durability properties of concrete at high temperatures, *SN Appl. Sci.* 1 (2019) 1–11, <https://doi.org/10.1007/s42452-019-0739-2>.
- [123] E. Emam, S. Yehia, Performance of concrete containing zeolite as a supplementary cementitious performance of concrete containing zeolite as a supplementary cementitious material, *Int. Res. J. Eng. Technol.* 4 (2018) 1619–1625.
- [124] T. Markiv, K. Sobol, W. Franus, Mechanical and durability properties of concretes incorporating natural zeolite, *Arch. Civ. Mech. Eng.* 6 (2016), <https://doi.org/10.1016/j.acme.2016.03.013>.
- [125] F.A. Sabet, N.A. Libre, M. Shekarchi, Mechanical and durability properties of self consolidating high performance concrete incorporating natural zeolite, silica fume and fly ash, *Construct. Build. Mater.* 44 (2013) 175–184, <https://doi.org/10.1016/j.conbuildmat.2013.02.069>.
- [126] M. Nas, Ş. Kurbetci, Mechanical, durability and microstructure properties of concrete containing natural zeolite, *Comput. Concr.* 22 (2018) 449–459, <https://doi.org/10.12989/cac.2018.22.5.449>.
- [127] D. Nasr, B. Behforouz, P.R. Borujeni, S.A. Borujeni, B. Zehtab, Effect of nano-silica on mechanical properties and durability of self-compacting mortar containing natural zeolite: experimental investigations and artificial neural network modeling, *Construct. Build. Mater.* 229 (2019), 116888, <https://doi.org/10.1016/j.conbuildmat.2019.116888>.
- [128] A.A. Shahmansouri, H. Akbarzadeh Bengar, H. AzariJafari, Life cycle assessment of eco-friendly concrete mixtures incorporating natural zeolite in sulfate-aggressive environment, *Construct. Build. Mater.* 268 (2021), 121136, <https://doi.org/10.1016/j.conbuildmat.2020.121136>.
- [129] H. Molaabasi, M. Saberian, J. Li, Prediction of compressive and tensile strengths of zeolite-cemented sand using porosity and composition, *Construct. Build. Mater.* 202 (2019) 784–795, <https://doi.org/10.1016/j.conbuildmat.2019.01.065>.
- [130] E. Mohseni, W. Tang, H. Cui, Chloride diffusion and acid resistance of concrete containing zeolite and tuff as partial replacements of cement and sand, *Materials (basel)*, <https://doi.org/10.3390/ma10040372>, 2017.
- [131] F. Jokar, M. Khorram, G. Karimi, N. Hataf, Experimental investigation of mechanical properties of crumbed rubber concrete containing natural zeolite, *Construct. Build. Mater.* 208 (2019) 651–658, <https://doi.org/10.1016/j.conbuildmat.2019.03.063>.
- [132] S. Loganayagan, N.C. Mohan, S. Dhivyabharathi, Sugarcane bagasse ash as alternate supplementary cementitious material in concrete, *Mater. Today Proc.* (2020) 3–6, <https://doi.org/10.1016/j.matpr.2020.03.060>.
- [133] N.S. Msinjili, W. Schmidt, A. Rogge, Rice husk ash as a sustainable supplementary cementitious material for improved concrete properties, *African J. Sci. Technol. Innov. Dev.* (2018) 1–9, <https://doi.org/10.1080/20421338.2018.1513895>.
- [134] S.K. Vijaya, K. Jagadeeswari, K. Srinivas, Behaviour of M60 grade concrete by partial replacement of cement with fly ash, rice husk ash and silica fume, *Mater. Today Proc.* 37 (2020) 2104–2108, <https://doi.org/10.1016/j.matpr.2020.07.523>.
- [135] A.A.K. Al-Alwan, M. Al-Bazoon, F.I. Mussa, H.A. Alalwan, M. Hatem Shadhar, M.M. Mohammed, M.F. Mohammed, The impact of using rice husk ash as a replacement material in concrete: an experimental study, *J. King Saud Univ. - Eng. Sci.* (2022) 6, <https://doi.org/10.1016/j.jksues.2022.03.002>.
- [136] M. Jamil, M.N.N. Khan, M.R. Karim, A.B.M.A. Kaish, M.F.M. Zain, Physical and chemical contributions of Rice Husk Ash on the properties of mortar, *Construct. Build. Mater.* 128 (2016) 185–198, <https://doi.org/10.1016/j.conbuildmat.2016.10.029>.
- [137] K. Kunchariyakun, S. Asavapisit, K. Sombatsompop, Properties of autoclaved aerated concrete incorporating rice husk ash as partial replacement for fine aggregate, *Cem. Concr. Compos.* 55 (2015) 11–16, <https://doi.org/10.1016/j.cemconcomp.2014.07.021>.
- [138] E. Mohseni, F. Naseri, R. Amjadi, M.M. Khotbhsara, M.M. Ranjbar, Microstructure and durability properties of cement mortars containing nano-TiO₂ and rice husk ash, *Construct. Build. Mater.* 114 (2016) 656–664, <https://doi.org/10.1016/j.conbuildmat.2016.03.136>.
- [139] T.S. Priya, A. Mehra, S. Jain, K. Kakria, Effect of graphene oxide on high - strength concrete induced with rice husk ash : mechanical and durability performance, *Innov. Infrastruct. Solut.* (2021), <https://doi.org/10.1007/s41062-020-00378-9>.
- [140] J.C. Arenas-piedrahita, P. Montes-garcía, J.M. Mendoza-rangel, H.Z.L. Calvo, Mechanical and durability properties of mortars prepared with untreated sugarcane bagasse ash and untreated fly ash, *Construct. Build. Mater.* 105 (2016) 69–81, <https://doi.org/10.1016/j.conbuildmat.2015.12.047>.
- [141] M.V.S. Reddy, K. Ashalatha, M. Madhuri, P. Sumalatha, Utilization of sugarcane bagasse ash (SCBA) in concrete by partial replacement of cement, *IOSR J. Mech. Civ. Eng.* 12 (2015) 12–16, <https://doi.org/10.9790/1684-12661216>.
- [142] M.F. Nuruddin, A. Abd. E. Hussein, H. Al Mattarneh, Effects of Sugarcane Bagasse Ash on the Properties of Concrete, 2016, pp. 1–10.
- [143] P. Jha, A.K. Sachan, R.P. Singh, Agro-waste sugarcane bagasse ash (ScBA) as partial replacement of binder material in concrete, *Mater. Today Proc.* (2021), <https://doi.org/10.1016/j.matpr.2020.09.751>.
- [144] M. Gesoğlu, E. Güneş, R. Alzebaree, K. Mermerdaş, Effect of silica fume and steel fiber on the mechanical properties of the concretes produced with cold bonded fly ash aggregates, *Construct. Build. Mater.* 40 (2013) 982–990, <https://doi.org/10.1016/j.conbuildmat.2012.11.074>.
- [145] S. Ahmad, I. Hakeem, M. Maslehuddin, Development of UHPC mixtures utilizing natural and industrial waste materials as partial replacements of silica fume and sand, *Sci. World J.* 2014 (2014), <https://doi.org/10.1155/2014/713531>.
- [146] M. Amin, B.A. Tayeh, Materials Investigating the mechanical and microstructure properties of fi bre-reinforced lightweight concrete under elevated temperatures, *Case Stud. Constr. Mater.* 13 (2020), e00459, <https://doi.org/10.1016/j.cscm.2020.e00459>.
- [147] M.A. Sanjuán, E. Menéndez, H. Recino, Mechanical performance of portland cement, coarse silica fume, and limestone (PC-SF-ls) ternary portland cements, *Materials* 15 (2022) 1–12, <https://doi.org/10.3390/ma15082933>.
- [148] K.I.M. Ibrahim, Recycled waste glass powder as a partial replacement of cement in concrete containing silica fume and fly ash, *Case Stud. Constr. Mater.* 15 (2021), e00630, <https://doi.org/10.1016/j.cscm.2021.e00630>.
- [149] R. Hussian, Use of cement kiln dust and silica fume as partial replacement for cement in concrete, *IOP Conf. Ser. Earth Environ. Sci.* 877 (2021), <https://doi.org/10.1088/1755-1315/877/1/012045>.
- [150] M. Uysal, M.M. Al-mashhadani, Y. Aygörmec, O. Canpolat, Effect of using colemanite waste and silica fume as partial replacement on the performance of metakaolin-based geopolymer mortars, *Construct. Build. Mater.* 176 (2018) 271–282, <https://doi.org/10.1016/j.conbuildmat.2018.05.034>.
- [151] N.A. Soliman, A. Tagnit-Hamou, Partial substitution of silica fume with fine glass powder in UHPC: filling the micro gap, *Construct. Build. Mater.* 139 (2017) 374–383, <https://doi.org/10.1016/j.conbuildmat.2017.02.084>.
- [152] N. Parthasarathi, M. Prakash, K.S. Satyanarayanan, Experimental study on partial replacement of cement with egg shell powder and silica fume, *Rasayan J. Chem.* 10 (2017) 442–449, <https://doi.org/10.7324/RJC.2017.1021689>.

- [153] Y. Wang, S. Zhang, D. Niu, L. Su, D. Luo, Effects of silica fume and blast furnace slag on the mechanical properties and chloride ion distribution of coral aggregate concrete, *Construct. Build. Mater.* 214 (2019) 648–658, <https://doi.org/10.1016/j.conbuildmat.2019.04.149>.
- [154] S.K. Das, S.M. Mustakim, A. Adesina, J. Mishra, T.S. Alomayri, H.S. Assaedi, C.R. Kaze, Fresh, strength and microstructure properties of geopolymer concrete incorporating lime and silica fume as replacement of fly ash, *J. Build. Eng.* 32 (2020), 101780, <https://doi.org/10.1016/j.jobbe.2020.101780>.
- [155] M. Abdi Moghadam, R.A. Izadifard, Effects of zeolite and silica fume substitution on the microstructure and mechanical properties of mortar at high temperatures, *Construct. Build. Mater.* 253 (2020), 119206, <https://doi.org/10.1016/j.conbuildmat.2020.119206>.
- [156] S. Zhao, Q. Zhang, Effect of silica fume in concrete on mechanical properties and dynamic behaviors under impact loading, *Materials* 12 (2019), <https://doi.org/10.3390/ma12193263>.
- [157] M. Saillio, S. Pradelle, M. Bertin, Cement and Concrete Research Effect of supplementary cementitious materials on carbonation of cement pastes, *Cement Concr. Res.* 142 (2021), <https://doi.org/10.1016/j.cemconres.2021.106358>.
- [158] M. Raghav, T. Park, H. Yang, S. Lee, S. Karthick, H. Lee, Review of the effects of supplementary cementitious materials and chemical additives on the physical, mechanical and durability properties of hydraulic concrete, *MDPI- Mater.* 2021, <https://doi.org/10.3390/ma14237270%0A>.
- [159] M. Thiedeitz, W. Schmidt, Performance of rice husk ash as supplementary cementitious material after production in the field and in the lab, *Mater. MDPI* (2020) 1–17, <https://doi.org/10.3390/ma13194319>.
- [160] F. Lollini, E. Redaelli, L. Bertolini, A study on the applicability of the efficiency factor of supplementary cementitious materials to durability properties, *Construct. Build. Mater.* 120 (2016) 284–292, <https://doi.org/10.1016/j.conbuildmat.2016.05.031>.
- [161] M. Elsayed, B.A. Tayeh, Y.I. Abu, N.A. El-nasser, M. Abou, Shear strength of eco-friendly self-compacting concrete beams containing ground granulated blast furnace slag and fly ash as cement replacement, *Case Stud. Constr. Mater.* 17 (2022), e01354, <https://doi.org/10.1016/j.cscm.2022.e01354>.
- [162] G.L. Golewski, Combined effect of coal fly ash (CFA) and nanosilica (nS) on the strength parameters and microstructural properties of eco-friendly concrete, *Energies* 16 (2023) 452, <https://doi.org/10.3390/en16010452>.
- [163] P. Lorca, R. Calabuig, J. Benlloch, L. Soriano, J. Payá, Microconcrete with partial replacement of Portland cement by fly ash and hydrated lime addition, *Mater. Des.* 64 (2014) 535–541, <https://doi.org/10.1016/j.matdes.2014.08.022>.
- [164] E. Menéndez, A.M. Álvaro, M.T. Hernández, J.L. Parra, New methodology for assessing the environmental burden of cement mortars with partial replacement of coal bottom ash and fly ash, *J. Environ. Manag.* 133 (2014) 275–283, <https://doi.org/10.1016/j.jenvman.2013.12.009>.
- [165] Y. Park, A. Abolmaali, Y.H. Kim, M. Ghahremannejad, Compressive strength of fly ash-based geopolymer concrete with crumb rubber partially replacing sand, *Construct. Build. Mater.* 118 (2016) 43–51, <https://doi.org/10.1016/j.conbuildmat.2016.05.001>.
- [166] M.H.F. de Medeiros, J.W. Raisdorfer, J. Hoppe Filho, R.A. Medeiros-Junior, Partial replacement and addition of fly ash in Portland cement: influences on carbonation and alkaline reserve, *J. Build. Pathol. Rehabil.* 2 (2017) 1–9, <https://doi.org/10.1007/s41024-017-0023-z>.
- [167] A. Mehta, R. Siddique, Properties of low-calcium fly ash based geopolymer concrete incorporating OPC as partial replacement of fly ash, *Construct. Build. Mater.* 150 (2017) 792–807, <https://doi.org/10.1016/j.conbuildmat.2017.06.067>.
- [168] E.C. Concrete, P. Alcohol, T. Author, C.C. By-nc-nd, I. The, E.C. Composite, Mechanical and deformation properties of rubberized engineered cementitious composite (ECC), *Case Stud. Constr. Mater.* J. 13 (2020), <https://doi.org/10.1016/j.cscm.2020.e00385>.
- [169] Y. Nurchasanah, Characteristic of “Tulakan” soil as natural pozzolan to substitute portland cement as construction material, *Procedia Eng.* 54 (2013) 764–773, <https://doi.org/10.1016/j.proeng.2013.03.070>.
- [170] V. Swathi, S.S. Asadi, An influence of pozzolanic materials with hybrid fibers on structural performance of concrete: a review, *Mater. Today Proc.* 43 (2020) 1956–1959, <https://doi.org/10.1016/j.matpr.2020.11.260>.
- [171] E. Küçükyıldırım, B. Uzal, Characteristics of calcined natural zeolites for use in high-performance pozzolan blended cements, *Construct. Build. Mater.* J. 73 (2014) 229–234, <https://doi.org/10.1016/j.conbuildmat.2014.09.081>.
- [172] H. Bolat, A. Vural, E. Tuncer, Investigation of pozzolanic activity of volcanic rocks from the northeast of the Black sea, *Sci. Eng. Compos. Mater.* (2014), <https://doi.org/10.1515/secm-2014-0092>.
- [173] N. Tebbal, Z. El Abidine Rahmouni, Rheological and mechanical behavior of mortars with metakaolin formulation, *Procedia Comput. Sci.* 158 (2019) 45–50, <https://doi.org/10.1016/j.procs.2019.09.026>.
- [174] M. Karthikeyan, P.R. Ramachandran, A. Nandhini, R. Vinodha, Application on partial substitute of cement by bentonite in concrete, *Int. J. ChemTech Res.* 8 (2015) 384–388.
- [175] B. Alam, M. Ashraf, Combined effect of bentonite and silica fume properties of high performance, *Int. J. OfAdvanced Struct. Geotech. Eng.* 2 (2013).
- [176] J. Chamundeswari, Experimental study on partial replacement of cement by bentonite in paverblock, *Int. J. Eng. Trends Technol.* 3 (2012) 41–47, <http://www.ijettjournal.org>.
- [177] P. Chanakya, D. Behera, Experimental study on compressive strength of concrete by partial replacement of cement with metakaolin, *Int. J. Sci. Eng. Technol. Res.* 5 (2016) 5354–5358.
- [178] M. Valipour, F. Pargar, M. Shekarchi, S. Khani, Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: a laboratory study, *Construct. Build. Mater.* 41 (2013) 879–888, <https://doi.org/10.1016/j.conbuildmat.2012.11.054>.
- [179] A. Ergün, Effects of the Usage of Diatomite and Waste Marble Powder as Partial Replacement of Cement on the Mechanical Properties of Concrete, vol. 25, 2011, pp. 806–812, <https://doi.org/10.1016/j.conbuildmat.2010.07.002>.
- [180] N. Fezzioui, B. Amrane, K. Souici, B. Hami, S. Kennouche, B. Safi, M. Nadir, Effect of metakaolin as partially cement replacement on the compressive strength of standard mortars, *Rev. Rom. Ing. Civila/Romanian J. Civ. Eng.* 12 (2021) 268–280, <https://doi.org/10.37789/rjce.2021.12.2.6>.
- [181] R.P. Borg, A.M.M. Hamed, R. Edreis, A.M. Mansor, Characterization of Libyan metakaolin and its effects on the mechanical properties of mortar, *IOP Conf. Ser. Mater. Sci. Eng.* 442 (2018) 1–8, <https://doi.org/10.1088/1757-899X/442/1/012005>.
- [182] M.A. Ahmed, Structural performance of reinforced concrete beams with NanoMeta-kaolin in shear, *IOSR J. Mech. Civ. Eng.* 14 (2017) 88–96, <https://doi.org/10.9790/1684-1402048896>.
- [183] K. Nikhil, H. Ajay, Evaluation of strength of plain cement concrete with partial replacement of cement by meta kaolin & fly ash, *Int. J. Eng. Res. V4* (2015), <https://doi.org/10.17577/ijertv4is050860>.
- [184] M. Morsy, S. Alsayed, M. Aqel, Effect of nano-clay on mechanical properties and microstructure of ordinary Portland cement mortar, *Int. J. Civ. Environ. Eng. - IJCEE.* 10 (2010) 23–27, <https://www.researchgate.net/publication/284429895>.
- [185] T. Özturan, K. Mermerdaş, E. Güneyisi, M. Gesoğlu, T. Özturan, K. Mermerdaş, Comparing pozzolanic activity of metakaolin and calcined kaolin, and their effects on strength of concrete, 17–19, <https://www.researchgate.net/publication/282764072>, 2012.
- [186] M. Najimi, N. Ghafoori, Engineering properties of natural pozzolan/slag based alkali-activated concrete, *Construct. Build. Mater.* 208 (2019) 46–62, <https://doi.org/10.1016/j.conbuildmat.2019.02.107>.
- [187] H. Siad, H.A. Mesbah, S.K. Bernard, Influence of natural pozzolan on the behavior of self-compacting concrete under sulphuric and hydrochloric acid attacks, comparative study, *Arabian J. Sci. Eng.* 35 (2010) 183–195.
- [188] R.E. Rodríguez-Camacho, R. Uribe-Afif, Importance of using the natural pozzolans on concrete durability, *Cement Concr. Res.* 32 (2002) 1851–1858.
- [189] J. Mirza, M. Riaz, A. Naseer, F. Rehman, A.N. Khan, Q. Ali, Pakistani bentonite in mortars and concrete as low cost construction material, *Appl. Clay Sci.* 45 (2009) 220–226, <https://doi.org/10.1016/j.clay.2009.06.011>.
- [190] A. Shukla, N. Gupta, A. Gupta, R. Goel, S. Kumar, Natural pozzolans a comparative study: a review, *IOP Conf. Ser. Mater. Sci. Eng.* 804 (2020), <https://doi.org/10.1088/1757-899X/804/1/012040>.
- [191] R. Robayo-salazar, R.M. De Gutiérrez, F. Puertas, Alkali-activated binary concrete based on a natural pozzolan : physical , mechanical and microstructural characterization, *Mater. Construcción* 69 (2019), <https://doi.org/10.3989/mc.2019.06618>.
- [192] S. Ahmad, K.O. Mohaisen, S.K. Adekunle, S.U. Al-dulaijan, M. Maslehuddin, Influence of admixing natural pozzolan as partial replacement of cement and microsilica in UHPC mixtures, *Construct. Build. Mater.* 198 (2019) 437–444, <https://doi.org/10.1016/j.conbuildmat.2018.11.260>.

- [193] H.L.A.M. Siva Parvathi¹, K. Yogesh², M. NikhilSuhass³, Evaluation of strength of PCC with partial replacement of cement by meta kaolin and fly ash, *Int. J. Sci. Dev. Res.* V4 (2019) 395–400, <https://doi.org/10.17577/ijertv4is050860>.
- [194] D. Nagrockiene, G. Girskas, Research into the properties of concrete modified with natural zeolite addition, *Construct. Build. Mater.* 113 (2016) 964–969, <https://doi.org/10.1016/j.conbuildmat.2016.03.133>.
- [195] M. Abith, L. Jolly, R.A. Mathiyalagan, Effect of partial replacement of cement with metakaolin and rice husk ash on the strength and durability properties of high strength concrete, *Int. J. Adv. Res. Trends Eng. Technol.* 3 (2016) 16–26.
- [196] X. Man, M.A. Haque, B. Chen, Engineering properties and microstructure analysis of magnesium phosphate cement mortar containing bentonite clay, *Construct. Build. Mater.* 227 (2019), 116656, <https://doi.org/10.1016/j.conbuildmat.2019.08.037>.
- [197] A. Anand, S. Kumari, A study on strength and durability of concrete by partial replacement of cement with bentonite, *Int. Res. J. Mod. Eng. Technol. Sci.* 4 (2022) 3964–3967.
- [198] J. Wei, B. Gencturk, Cement and Concrete Research Hydration of ternary Portland cement blends containing metakaolin and sodium bentonite, *Cement Concr. Res.* 123 (2019), 105772, <https://doi.org/10.1016/j.cemconres.2019.05.017>.
- [199] I.U. Haq, Polypropylene concrete containing bentonite & silica fume, in: *3rd Conf. Sustain. Civ. Eng.*, 2022.
- [200] S.U. Rehman, M. Yaqub, M. Noman, B. Ali, M. Nasir, A. Khan, M. Fahad, M.M. Abid, A. Gul, The influence of thermo-mechanical activation of bentonite on the mechanical and durability performance of concrete, *Appl. Sci. MDPI* (2019), <https://doi.org/10.3390/app9245549>.
- [201] Y. Xie, J. Li, Z. Lu, J. Jiang, Y. Niu, Preparation and properties of ultra-lightweight EPS concrete based on pre-saturated bentonite, *Construct. Build. Mater.* 195 (2019) 505–514, <https://doi.org/10.1016/j.conbuildmat.2018.11.091>.
- [202] G.U. Alaneme, E.M. Mbadike, Optimisation of strength development of bentonite and palm bunch ash concrete using fuzzy logic, *Int. J. Sustain. Eng.* 14 (2021) 835–851, <https://doi.org/10.1080/19397038.2021.1929549>.
- [203] J. Ahmad, K.J. Kontoleon, M.Z. Al-Mulali, S. Shaik, M.H. El Ouni, M.A. El-Shorbagy, Partial substitution of binding material by bentonite clay (BC) in concrete: a review, *Buildings* 12 (2022), <https://doi.org/10.3390/buildings12050634>.
- [204] M. Aravindhraj, B.T. Sapna, Influence of bentonite in strength and durability of high performance concrete, *Int. Res. J. Eng. Technol.* 3 (2016).
- [205] K.S. Sudheer, P. Sai, K. Polisetty, M.A.K. Reddy, R.R. Vummaneni, A study on durability of concrete by partial replacement of cement with bentonite, *Int. J. ChemTech Res.* 10 (2017).
- [206] S.U. Rehman, M. Yaqub, T. Ali, K. Shahzada, S.W. Khan, M. Noman, Durability of mortars modified with calcined montmorillonite clay, *Civ. Eng. J.* 5 (2019) 1490–1505, <https://doi.org/10.28991/cej-2019-03091347>.
- [207] C. Yu, G. Li, J. Gao, B. Lan, Q. Wei, D. Xu, Effect of bentonite on the performance of the limestone manufactured-sand mortar, *Appl. Mech. Mater.* 360 (2013) 1374–1378, <https://doi.org/10.4028/www.scientific.net/AMM.357-360.1374>.
- [208] M. Habib, M. Saad, N. Abbas, Evaluation of mechanical and durability aspects of self-compacting concrete by using thermo-mechanical activation of bentonite, *Eng. Proceeding- MDPI* 22 (2022), <https://doi.org/10.3390/engproc2022022017>.
- [209] R. Devi, Partial replacement of cement with bentonite clay in concrete, *JournalNX- A Multidiscip. Peer.* 4 (2018) 12–14.
- [210] M. Chandrakanth, N.S.P.C. Rao, Experimental studies on concrete with bentonite as mineral admixture, *GRD J. Eng.* 1 (2016) 7–10.
- [211] S.U. Khaliq, I. Jamil, H. Ullah, Evaluating permeability and mechanical properties of waste marble dust mix concrete and bentonite mix concrete, *Streamlining Inf. Transf. between Constr. Struct. Eng.* (2018), <https://doi.org/10.14455/ISEC.res.2018.96>.
- [212] Z.E.-A. Laidan, Y. Ouldkhaoua, M. Sahraoui, B. Benabed, Feasibility of marble powder and calcined bentonite in SCM as partial substitution of cement for sustainable production, *J. Silic. Based Compos. Mater.* 74 (2022) 61–66.
- [213] P. Ashish, C. Srinivasarao, Influence of bentonite as partial replacement of cement in basalt fiber concrete, *Mater. Sci. Eng. Pap.* (2021), <https://doi.org/10.1088/1757-899X/1185/1/012015>.
- [214] M.S. Ali, R. Arsalan, S. Khan, T.Y. Lo, Utilization of Pakistani bentonite as partial replacement of cement in concrete, *Construct. Build. Mater.* 30 (2012) 237–242, <https://doi.org/10.1016/j.conbuildmat.2011.11.021>.
- [215] C. Vijay, M. Achyutha Kumar Reddy, Optimization of bentonite modified cement mortar parameters at elevated temperatures using RSM, *IOP Conf. Ser. Mater. Sci. Eng.* 1197 (2021), 012040, <https://doi.org/10.1088/1757-899X/1197/1/012040>.
- [216] J. Rajczyk, B. Langier, Concrete composite properties with modified sodium bentonite in material application engineering, *Adv. Mater. Res.* 583 (2012) 154–157, <https://doi.org/10.4028/www.scientific.net/AMR.583.154>.
- [217] S. Ghonaim, R. Morsy, Study of bentonite usage in environmentally friendly concrete, *J. Al-Azhar Univ. Eng. Sect.* 15 (2020) 1012–1024, <https://doi.org/10.21608/aej.2020.120366>.
- [218] H.H. Lee, C. Wang, P. Chung, Experimental study on the strength and durability for slag cement mortar with bentonite, *Appl. Sci.* (2021), <https://doi.org/10.3390/app11031176>.
- [219] C. Andrade, A. Martínez-serrano, M.Á. Sanjuán, J.A. Tenorio Ríos, Decrease of carbonation, sulfate and chloride ingress due to the substitution of cement by 10% of NON calcined bentonite, *Materials* 14 (2021) 1–18, <https://doi.org/10.3390/ma14051300>.
- [220] N. Lemonis, P.E. Tsakiridis, N.S. Katsiotis, S. Antiohos, D. Papageorgiou, M.S. Katsiotis, M. Beazi-Katsioti, Hydration study of ternary blended cements containing ferronickel slag and natural pozzolan, *Construct. Build. Mater.* 81 (2015) 130–139, <https://doi.org/10.1016/j.conbuildmat.2015.02.046>.
- [221] S. Oumnih, N. Bekkouch, E.K. Gharibi, N. Fagel, K. Elhamouti, M. El Ouahabi, Phosphogypsum waste as additives to lime stabilization of bentonite, *Sustain. Environ. Res.* (2019) 1–10, <https://doi.org/10.1186/s42834-019-0038-z>.
- [222] A.M. Rodrigues, F.P. da Costa, S.L.D. Beltrão, J.V. Fernandes, R.R. Menezes, G. de A. Neves, Development of eco-friendly mortars produced with kaolin processing waste: durability behavior viewpoint, *Sustain. Times* 13 (2021) 1–15, <https://doi.org/10.3390/su132011395>.
- [223] L. Dembovska, D. Bajare, I. Pundiene, L. Vitola, Effect of pozzolanic additives on the strength development of high performance concrete, *Procedia Eng.* 172 (2017) 202–210, <https://doi.org/10.1016/j.proeng.2017.02.050>.
- [224] R. Fernández, L. González, A.I. Ruiz, J. Cuevas, Nature of C (A) -S-H phases formed in the reaction bentonite/portlandite, *J. Geochemistry.* 2014 (2014), <https://doi.org/10.1155/2014/145425>.
- [225] A. Oluwaseun, W. Kehinde, E. Rotimi, J. Musyoka, C. Kambole, Experimental investigation of modified bentonite clay-crumb rubber concrete, *Construct. Build. Mater.* 233 (2020), 117187, <https://doi.org/10.1016/j.conbuildmat.2019.117187>.
- [226] Y. Chen, Z. Sun, Y. Cui, W. Ye, Q. Liu, Effect of cement solutions on the swelling pressure of compacted GMZ bentonite at different temperatures, *Construct. Build. Mater.* 229 (2019), 116872, <https://doi.org/10.1016/j.conbuildmat.2019.116872>.
- [227] Z.E.A. Laidani, B. Benabed, R. Abousnina, M.K. Gueddouda, M.J. Khatib, Potential pozzolanicity of Algerian calcined bentonite used as cement replacement: optimisation of calcination temperature and effect on strength of self-compacting mortars, *Eur. J. Environ. Civ. Eng.* 26 (2022) 1379–1401, <https://doi.org/10.1080/19648189.2020.1713898>.
- [228] A. Busari, J. Akinmusuru, B. Dahunsi, Strength and durability properties of concrete using metakaolin as a sustainable material: review of literatures, *Int. J. Civ. Eng. Technol.* 10 (2019) 1893–1902.
- [229] Z. Yahya, M.M.A.B. Abdullah, N. Mohd Ramli, D.D. Burduhos-Nergis, R. Abd Razak, Influence of kaolin in fly ash based geopolymer concrete: destructive and non-destructive testing, *IOP Conf. Ser. Mater. Sci. Eng.* 374 (2018), <https://doi.org/10.1088/1757-899X/374/1/012068>.
- [230] O.O. Ofuyatan, A.M. Olowofoyeku, S.S. Vivek, B. Karthikeyan, Physical and mechanical properties of self-compacting concrete containing superplasticizer and metakaolin Physical and mechanical properties of self-compacting concrete containing superplasticizer and metakaolin, *IOP Conf. Ser. Mater. Sci. Eng.* (2017), <https://doi.org/10.1088/1757-899X/271/1/012004>.
- [231] M.S. Muhd Norhasri, M.S. Hamidah, A. Mohd Fadzil, A.G. Abd Halim, M.R. Zaidi, Fresh state behaviour of cement paste containing nano kaolin, *Adv. Mater. Res.* 925 (2014) 28–32, <https://doi.org/10.4028/www.scientific.net/AMR.925.28>.
- [232] S. Elavarasan, A.K. Priya, N. Ajai, S. Akash, T.J. Annie, G. Bhuvana, Experimental study on partial replacement of cement by metakaolin and GGBS, *Mater. Today Proc.* 37 (2020) 3527–3530, <https://doi.org/10.1016/j.matpr.2020.09.416>.

- [233] E. William, C.I.Z.S. Akobo, B.E. Ngeke, Effect of metakaolin as a partial replacement for cement on the compressive strength of high strength concrete at varying water/binder ratios, *Int. J. Civ. Eng.* 6 (2019) 1–6, <https://doi.org/10.14445/23488352/ijce-v6i1p101>.
- [234] F. Arslan, A. Benli, M. Karatas, Effect of high temperature on the performance of self-compacting mortars produced with calcined kaolin and metakaolin, *Construct. Build. Mater.* 256 (2020), 119497, <https://doi.org/10.1016/j.conbuildmat.2020.119497>.
- [235] B. Ilić, V. Radonjanin, M. Malešev, M. Zdujić, A. Mitrović, Study on the addition effect of metakaolin and mechanically activated kaolin on cement strength and microstructure under different curing conditions, *Construct. Build. Mater.* 133 (2017) 243–252, <https://doi.org/10.1016/j.conbuildmat.2016.12.068>.
- [236] K. Ram, M. Serdar, D. Londono-Zuluaga, K. Scrivener, The effect of pore microstructure on strength and chloride ingress in blended cement based on low kaolin clay, *Case Stud. Constr. Mater.* 17 (2022), e01242, <https://doi.org/10.1016/j.cscm.2022.e01242>.
- [237] O. Karahan, K.M.A. Hossain, E. Ozbay, M. Lachemi, E. Sancak, Effect of metakaolin content on the properties self-consolidating lightweight concrete, *Construct. Build. Mater.* 31 (2012) 320–325, <https://doi.org/10.1016/j.conbuildmat.2011.12.112>.
- [238] M. Bediako, S.K.Y. Gawu, A.A. Adjaottor, J.S. Ankrah, Early and late strength characterization of portland cement containing calcined low-grade kaolin clay, in: *Hindawi Publ. Corp. Eng. (United Kingdom)*. 2016, 2016, <https://doi.org/10.1155/2016/7210891>.
- [239] M.S. Morsy, H. Shoukry, M.M. Mokhtar, A.M. Ali, S.A. El-Khodary, Facile production of nano-scale metakaolin: an investigation into its effect on compressive strength, pore structure and microstructural characteristics of mortar, *Construct. Build. Mater.* 172 (2018) 243–250, <https://doi.org/10.1016/j.conbuildmat.2018.03.249>.
- [240] R. Siddique, Effect of volcanic ash on the properties of cement paste and mortar, *Resour. Conserv. Recycl.* 56 (2011) 66–70, <https://doi.org/10.1016/j.resconrec.2011.09.005>.
- [241] K.M.A. Hossain, M. Lachemi, Strength, durability and micro-structural aspects of high performance volcanic ash concrete, *Cement Concr. Res.* 37 (2007) 759–766, <https://doi.org/10.1016/j.cemconres.2007.02.014>.
- [242] A. Naseer, A. Jabbar, A.N. Khan, Q. Ali, Z. Hussain, J. Mirza, Performance of Pakistani volcanic ashes in mortars and concrete, *Can. J. Civ. Eng.* 35 (2008) 1435–1445, <https://doi.org/10.1139/L08-093>.
- [243] K. Kupwade-Patil, C. De Wolf, S. Chin, J. Ochsendorf, A.E. Hajiah, A. Al-Mumin, O. Büyüköztürk, Impact of embodied energy on materials/buildings with partial replacement of ordinary portland cement (OPC) by natural pozzolanic volcanic ash, *J. Clean. Prod.* 177 (2018) 547–554, <https://doi.org/10.1016/j.jclepro.2017.12.234>.
- [244] K. Khan, M.N. Amin, M. Usman, M. Imran, M.A. Al-faiad, F.I. Shalabi, Effect of fineness and heat treatment on the pozzolanic activity of natural volcanic ash for its utilization as supplementary cementitious materials, *Crystals* (2022), <https://doi.org/10.3390/cryst12020302>.
- [245] S. Hammat, B. Menadi, S. Kenai, C. Thomas, M.S. Kirgiz, A.G. de Sousa Galdino, The effect of content and fineness of natural pozzolana on the rheological, mechanical, and durability properties of self-compacting mortar, *J. Build. Eng.* 44 (2021), 103276, <https://doi.org/10.1016/j.jobte.2021.103276>.
- [246] S. Bechar, D. Zerrouki, Effect of natural pozzolan on the fresh and hardened cement slurry properties for cementing oil well, *World J. Eng.* 4 (2018) 513–519, <https://doi.org/10.1108/WJJE-10-2017-0337>.
- [247] M.N. Amin, M.F. Javed, K. Khan, F.I. Shalabi, M.G. Qadir, SS symmetry modeling compressive strength of eco-friendly volcanic ash mortar using artificial neural networking, *Symmetry MDPI* (2021), <https://doi.org/10.3390/sym13112009>.
- [248] M.M. Keshta, M.M.Y. Elshikh, M.A. Elrahman, O. Youssf, Utilizing of magnetized water in enhancing of volcanic concrete characteristics, *J. Compos. Sci.* (2022), <https://doi.org/10.3390/jcs6100320>.
- [249] A.M. Zeyad, H.M. Magbool, B.A. Tayeh, A. Rangel, G. De Azevedo, A. Abutaleb, Q. Hussain, Materials Production of geopolymer concrete by utilizing volcanic pumice dust, *Case Stud. Constr. Mater.* 16 (2022), e00802, <https://doi.org/10.1016/j.cscm.2021.e00802>.
- [250] G. Girskas, G. Skripkiunas, G. Šahmenko, A. Korjakins, Durability of concrete containing synthetic zeolite from aluminum fluoride production waste as a supplementary cementitious material, *Construct. Build. Mater.* J. 117 (2016) 99–106, <https://doi.org/10.1016/j.conbuildmat.2016.04.155>.
- [251] S. More, T. Hirlekar, A review on causes, prevention, repair and maintenance of cracks in building (residential and commercial) *irjet journal a review on causes, prevention, repair and maintenance of cracks in building (residential and commercial)*, *Int. Res. J. Eng. Technol.* 9001 (2008) 1339. www.irjet.net.
- [252] H. Mola-Abasi, I. Shooshpasha, Influence of zeolite and cement additions on mechanical behavior of sandy soil, *J. Rock Mech. Geotech. Eng.* 8 (2016) 746–752, <https://doi.org/10.1016/j.jrmge.2016.01.008>.
- [253] A. Sicakova, M. Spak, M. Kozlovska, M. Kovac, Long-term properties of cement-based composites incorporating natural zeolite as a feature of progressive building material, *Adv. Mater. Sci. Eng.* 2017 (2017), <https://doi.org/10.1155/2017/7139481>.
- [254] A. Azad, A. Saedian, S. Mousavi, H. Karami, S. Farzin, V.P. Singh, Effect of zeolite and pumice powders on the environmental and physical characteristics of green concrete filters, *Construct. Build. Mater.* 240 (2020), 117931, <https://doi.org/10.1016/j.conbuildmat.2019.117931>.
- [255] M. Valipour, M. Yekkalari, M. Shekarchi, S. Panahi, Environmental assessment of green concrete containing natural zeolite on the global warming index in marine environments, *J. Clean. Prod.* 65 (2014) 418–423, <https://doi.org/10.1016/j.jclepro.2013.07.055>.
- [256] A.A. Ramezani-pour, R. Mousavi, M. Kalhori, J. Sobhani, M. Najimi, Micro and macro level properties of natural zeolite contained concretes, *Construct. Build. Mater.* 101 (2015) 347–358, <https://doi.org/10.1016/j.conbuildmat.2015.10.101>.
- [257] E. Vejmelková, D. Koňáková, M. Čáchová, M. Keppert, A. Hubáček, R. Černý, Application of zeolite as a partial replacement of cement in concrete production, *Appl. Mech. Mater.* 621 (2014) 30–34, <https://doi.org/10.4028/www.scientific.net/AMM.621.30>.
- [258] K. Samimi, S. Kamali-Bernard, A. Akbar Maghsoudi, M. Maghsoudi, H. Siad, Influence of pumice and zeolite on compressive strength, transport properties and resistance to chloride penetration of high strength self-compacting concretes, *Construct. Build. Mater.* 151 (2017) 292–311, <https://doi.org/10.1016/j.conbuildmat.2017.06.071>.
- [259] Z. Xuan, Z. Jun, Influence of zeolite addition on mechanical performance and shrinkage of high strength Engineered Cementitious Composites, *J. Build. Eng.* 36 (2021), 102124, <https://doi.org/10.1016/j.jobte.2020.102124>.
- [260] L. Pang, Z. Liu, D. Wang, M. An, Review on the application of supplementary cementitious materials in self-compacting concrete, *Crystals S* (2022), <https://doi.org/10.3390/cryst12020180>.
- [261] W. Xu, J.J. Chen, J. Wei, B. Zhang, X. Yuan, P. Xu, Q. Yu, J. Ren, Evaluation of inherent factors on flowability, cohesiveness and strength of cementitious mortar in presence of zeolite powder, *Construct. Build. Mater.* 214 (2019) 61–73, <https://doi.org/10.1016/j.conbuildmat.2019.04.115>.
- [262] K. Hung, T. Ling, U.J. Alengaram, S. Poh, C. Wah, Overview of supplementary cementitious materials usage in lightweight aggregate concrete, *Construct. Build. Mater.* 139 (2017) 403–418, <https://doi.org/10.1016/j.conbuildmat.2017.02.081>.
- [263] J.V. Patil, Partial replacement of cement by fly ash in concrete mix design, *Int. Res. J. Eng. Technol.* 4 (2017) 1148–1150.
- [264] D. Parthiban, D.S. Vijayan, R.S. Kumar, A.P. Santhu, G.A. Cherian, M. Ashiq, Materials Today : proceedings Performance evaluation of Fly ash based GPC with partial replacement of RHA as a cementitious material, *Mater. Today Proc.* (2020), <https://doi.org/10.1016/j.matpr.2020.05.244>.
- [265] A.M. Mohamed, R. Khallaf, Fly ash application as supplementary cementitious material : a review, *materials (basel)*, 1–23, <https://doi.org/10.3390/ma15072664>, 2022.
- [266] F. Moghaddam, V. Sirivivatnanon, K. Vessalas, The effect of fly ash fineness on heat of hydration, microstructure, flow and compressive strength of blended cement pastes, *Case Stud. Constr. Mater.* 10 (2019), e00218, <https://doi.org/10.1016/j.cscm.2019.e00218>.
- [267] W.E. Shaker, M.A. Qaidi, Bassam A. Tayeh, Hemn Unis Ahmed, A review of the sustainable utilisation of red mud and fly ash for the production of geopolymer composites, *Construct. Build. Mater.* 350 (2022), <https://doi.org/10.1016/j.conbuildmat.2022.128892>.
- [268] D.M. Gil, G.L. Golewski, Potential of siliceous fly ash and silica fume as a substitute for binder in cementitious concretes, in: *E3S Web Conf.*, 2018, pp. 4–11, <https://doi.org/10.1051/e3sconf/20184900030>.
- [269] A.S. Fariied, S.A. Mostafa, B.A. Tayeh, T.A. Tawfik, The effect of using nano rice husk ash of different burning degrees on ultra-high-performance concrete properties, *Construct. Build. Mater.* 290 (2021), 123279, <https://doi.org/10.1016/j.conbuildmat.2021.123279>.
- [270] G.L. Golewski, B. Szostak, Strength and microstructure of composites with cement matrixes modified by fly ash and active seeds of C-S-H phase, *Struct. Eng. Mech.* 82 (2022) 543–556, <https://doi.org/10.12989/sem.2022.82.4.543>.

- [271] T.G.S. Kiran, M.K.M. V Ratnam, Fly ash as a partial replacement of cement in concrete and durability study of fly ash in acidic (H 2 so 4) environment, *Int. J. Eng. Res.* 10 (2014) 1–13. www.ijerd.com.
- [272] D.K. Singh, S.R. Chaurasia, Effect on compressive strength of paver block by partial replacement of cement with fly ash, *Int. J. Sci. Technol. Eng. (IJSTE)* 2 (2016) 856–859.
- [273] W. Tariq, S.Q. Hussain, D.A. Nasir, N. Tayyab, S.H. Gillani, A. Rafiq, Experimental study on strength and durability of cement and concrete by partial replacement of fine aggregate with fly ash, *Earth Sci. Pakistan*. 1 (2017) 10–14, <https://doi.org/10.26480/esp.02.2017.10.14>.
- [274] G. Kumar, R. Saravanakumar, J. Anne Mary, Experimental study on partial replacement of cement by fly ash, *J. Adv. Res. Dyn. Control Syst.* 10 (2018) 1339–1347, <https://doi.org/10.17485/ijst/2015/v8i32/89008>.
- [275] L. Krishnaraj, P.T. Ravichandran, Investigation on grinding impact of fly ash particles and its characterization analysis in cement mortar composites, *Ain Shams Eng. J.* 10 (2019) 267–274, <https://doi.org/10.1016/j.asej.2019.02.001>.
- [276] M. Uma Maguesvari, T. Sundararajan, Influence of fly ash and fine aggregates on the characteristics of pervious concrete, *Int. J. Appl. Eng. Res.* 12 (2017) 1598–1609.
- [277] P. Dinakar, M. Kartik Reddy, M. Sharma, Behaviour of self compacting concrete using Portland pozzolana cement with different levels of fly ash, *Mater. Des.* 46 (2013) 609–616, <https://doi.org/10.1016/j.matdes.2012.11.015>.
- [278] A. Yerramala, R. Chandurdu, Influence of fly ash reinforcement on strength properties of cement mortar, *Int. J. Eng. Sci. Technol.* 4 (2015) 3657–3665.
- [279] N. Chousidis, E. Rakanta, I. Ioannou, G. Batis, Mechanical properties and durability performance of reinforced concrete containing fly ash, *Construct. Build. Mater.* 101 (2015) 810–817, <https://doi.org/10.1016/j.conbuildmat.2015.10.127>.
- [280] E. Arifi, E.N. Cahya, Evaluation of fly ash as supplementary cementitious material to the mechanical properties of recycled aggregate, *Int. J. GEOMATE* 18 (2020) 44–49, <https://doi.org/10.21660/2020.66.9270>.
- [281] N. Shaji, N. Holmes, M. Tyrer, Review of Fly-Ash as a Supplementary Cementitious Material, ARROW@TU Dublin, 2022, <https://doi.org/10.21427/CWYP-9447>.
- [282] C. Marthong, Effect of fly ash additive on concrete properties, *Int. J. Eng. Res. Appl. Wwww.Ijera.Com.* 2 (2012) 1986–1991. www.ijera.com.
- [283] S. Hn, A.R. Deotale, R.S. Sathawane, Effect of partial replacement of cement by fly ash, rice husk ash with using steel fiber in concrete, *Int. J. Sci. Eng. Res.* 3 (2012) 1–9. <http://www.ijser.org>.
- [284] A.A. Phul, M.J. Memon, S.N.R. Shah, A.R. Sandhu, GGBS and fly ash effects on compressive strength by partial replacement of cement concrete, *Civ. Eng. J.* 5 (2019) 913–921, <https://doi.org/10.28991/cej-2019-03091299>.
- [285] N. Saboo, S. Shivhare, K.K. Kori, A.K. Chandrappa, Effect of fly ash and metakaolin on pervious concrete properties, *Construct. Build. Mater.* 223 (2019) 322–328, <https://doi.org/10.1016/j.conbuildmat.2019.06.185>.
- [286] M.E. Ephraim, G.A. Akeke, J.O. Ukpta, Compressive strength of concrete with rice husk ash as partial replacement of ordinary Portland cement, *Sch. J. Eng. Res.* 1 (2012) 32–36.
- [287] S. Rukzon, P. Chindaprasit, R. Mahachai, Effect of grinding on chemical and physical properties of rice husk ash, *Int. J. Miner. Metall. Mater.* 16 (2009) 242–247, [https://doi.org/10.1016/S1674-4799\(09\)60041-8](https://doi.org/10.1016/S1674-4799(09)60041-8).
- [288] M.S. Meddah, T.R. Praveenkumar, M.M. Vijayalakshmi, S. Manigandan, R. Arunachalam, Mechanical and microstructural characterization of rice husk ash and Al₂O₃ nanoparticles modified cement concrete, *Construct. Build. Mater.* 255 (2020), 119358, <https://doi.org/10.1016/j.conbuildmat.2020.119358>.
- [289] B.S. Thomas, Green concrete partially comprised of rice husk ash as a supplementary cementitious material – a comprehensive review, *Renew. Sustain. Energy Rev.* (2017) 1–11, <https://doi.org/10.1016/j.rser.2017.10.081>.
- [290] F.C. Lo, M.G. Lee, S.L. Lo, Effect of coal ash and rice husk ash partial replacement in ordinary Portland cement on pervious concrete, *Construct. Build. Mater.* 286 (2021), 122947, <https://doi.org/10.1016/j.conbuildmat.2021.122947>.
- [291] T.R. Praveenkumar, M.M. Vijayalakshmi, M.S. Meddah, Strengths and durability performances of blended cement concrete with TiO₂ nanoparticles and rice husk ash, *Construct. Build. Mater.* 217 (2019) 343–351, <https://doi.org/10.1016/j.conbuildmat.2019.05.045>.
- [292] V. Kanthe, S. Deo, M. Murmu, Combine use of fly ash and rice husk ash in concrete to improve its properties, *Int. J. Eng. Trans. A Basics.* 31 (2018) 1012–1019, <https://doi.org/10.5829/ije.2018.31.07a.02>.
- [293] C. Fapohunda, B. Akinbile, A. Shittu, Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement – a review, *Int. J. Sustain. Built Environ.* 6 (2017) 675–692, <https://doi.org/10.1016/j.ijsbe.2017.07.004>.
- [294] R. Madandoust, M.M. Ranjbar, H.A. Moghadam, S.Y. Mousavi, Mechanical properties and durability assessment of rice husk ash concrete, *Biosyst. Eng.* 110 (2011) 144–152, <https://doi.org/10.1016/j.biosystemseng.2011.07.009>.
- [295] A.N. Givi, S.A. Rashid, F.N.A. Aziz, M.A.M. Salleh, Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete, *Construct. Build. Mater.* 24 (2010) 2145–2150, <https://doi.org/10.1016/j.conbuildmat.2010.04.045>.
- [296] N. Bheel, S.L. Meghwar, S.A. Abbasi, L.C. Marwari, J.A. Muger, R.A. Abbasi, Effect of rice husk ash and water-cement ratio on strength of concrete, *Civ. Eng. J.* 4 (2018) 2373, <https://doi.org/10.28991/cej-03091166>.
- [297] T. Abdalla, D. Otieno, S. Muse, M. Matallah, Results in Engineering Mechanical and durability properties of concrete incorporating silica fume and a high volume of sugarcane bagasse ash, *Results Eng* 16 (2022), <https://doi.org/10.1016/j.rineng.2022.100666>.
- [298] N.K. Krishna, S. Sandeep, K.M. Mini, Study on concrete with partial replacement of cement by rice husk ash, *IOP Conf. Ser. Mater. Sci. Eng.* (2016), <https://doi.org/10.1088/1757-899X/149/1/012109>.
- [299] T. Ali, A. Saand, D.K. Bangwar, A.S. Buller, Z. Ahmed, Mechanical and durability properties of aerated concrete incorporating rice husk ash (Rha) as partial replacement of cement, *Crystals* 11 (2021), <https://doi.org/10.3390/cryst11060604>.
- [300] N. Bheel, A.W. Abro, I.A. Shar, A.A. Dayo, S. Shaikh, Z.H. Shaikh, Use of rice husk ash as cementitious material in concrete, *Eng. Technol. Appl. Sci. Res.* 9 (2019) 4209–4212, <https://doi.org/10.48084/etasr.2746>.
- [301] P. Mamatha, S.M. V Narayana, T.N. Kumar, To evaluate the mechanical & durability properties of nano sugarcane bagasse ash in cement concrete, *IJSRST* 3 (2017) 425–430.
- [302] R. Siddique, K. Singh, M. Singh, V. Corinaldesi, A. Rajor, Properties of bacterial rice husk ash concrete, *Construct. Build. Mater.* 121 (2016) 112–119, <https://doi.org/10.1016/j.conbuildmat.2016.05.146>.
- [303] M.B. Ahsan, Z. Hossain, Supplemental use of rice husk ash (RHA) as a cementitious material in concrete industry, *Construct. Build. Mater.* 178 (2018) 1–9, <https://doi.org/10.1016/j.conbuildmat.2018.05.101>.
- [304] R.D.A. Hafez, B.A. Tayeh, K. Abdelsamie, Manufacturing nano novel composites using sugarcane and eggshell as an alternative for producing nano green mortar, *Environ. Sci. Pollut. Res.* 29 (2022) 34984–35000, <https://doi.org/10.1007/s11356-022-18675-4>.
- [305] I. Saad, O. Mohamed, B.A. Tayeh, B. Abdelsalam, Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete, *Construct. Build. Mater.* 235 (2020), 117541, <https://doi.org/10.1016/j.conbuildmat.2019.117541>.
- [306] H. Huang, X. Gao, H. Wang, H. Ye, Influence of rice husk ash on strength and permeability of ultra-high performance concrete, *Construct. Build. Mater.* 149 (2017) 621–628, <https://doi.org/10.1016/j.conbuildmat.2017.05.155>.
- [307] V. Vishwakarma, D. Ramachandran, N. Anbarasan, A.M. Rabel, Studies of rice husk ash nanoparticles on the mechanical and microstructural properties of the concrete, *Mater. Today Proc.* 3 (2016) 1999–2007, <https://doi.org/10.1016/j.matpr.2016.04.102>.
- [308] B.A. Tayeh, M. Hadzima-Nyarko, A.M. Zeyad, S.Z. Al-Harazin, Properties and durability of concrete with olive waste ash as a partial cement replacement, *Adv. Concr. Constr.* 11 (2021), <https://doi.org/10.12989/acc.2021.11.1.000>.
- [309] S.C. Paul, P.B.K. Mbewe, S.Y. Kong, Agricultural solid waste as source of supplementary cementitious materials in developing countries, *Mater. MDPI.* (2019), <https://doi.org/10.3390/ma12071112>.
- [310] H.M. Hamada, B. Skariah, B. Tayeh, F.M. Yahaya, Use of oil palm shell as an aggregate in cement concrete : a review, *Construct. Build. Mater.* 265 (2020), 120357, <https://doi.org/10.1016/j.conbuildmat.2020.120357>.

- [311] H.M. Hamada, A.A. Al-attar, F.M. Yahaya, K. Muthusamy, B.A. Tayeh, A.M. Humada, Materials Effect of High-Volume Ultra Fi Ne Palm Oil Fuel Ash on the Engineering and Transport Properties of Concrete, vol. 12, 2020, <https://doi.org/10.1016/j.cscm.2019.e00318>.
- [312] B.M. Hanumesh, B.K. Varun, B.A. Harish, The mechanical properties of concrete incorporating silica fume as partial replacement of cement, *Int. J. Emerg. Technol. Adv. Eng.* 5 (9. 5) (2015) 3–8.
- [313] R. Siddique, Utilization of silica fume in concrete: review of hardened properties, *Resour. Conserv. Recycl.* 55 (2011) 923–932, <https://doi.org/10.1016/j.resconrec.2011.06.012>.
- [314] M.I. Khan, R. Siddique, Utilization of silica fume in concrete: review of durability properties, *Resour. Conserv. Recycl.* 57 (2011) 30–35, <https://doi.org/10.1016/j.resconrec.2011.09.016>.
- [315] P. Singh, M.A. Khan, A. Kumar, The effect on concrete by partial replacement of cement by silica fume : a review, *Irjet* 3 (2016) 118–121. <file:///E:/Genius3/FYP/PDF/The Effect on Concrete by Partial Replac.pdf>.
- [316] DrR. Umamaheswari, M. Vigneshkuma, Experimental study on partial replacement of cement with egg shell powder and silica fume, *Int. Res. J. Eng. Technol.* 5 (2018), <https://doi.org/10.7324/RJC.2017.1021689>.
- [317] A. Sharma, Seema, effect of partial replacement of cement with silica fume on compressive strength of concrete, *Int. J. Res. Technol. Manag.* 1 (2012) 34–36.
- [318] S.M. Motahari Karein, A.A. Ramezani-pour, T. Ebadi, S. Isapour, M. Karakouzian, A new approach for application of silica fume in concrete: wet granulation, *Construct. Build. Mater.* 157 (2017) 573–581, <https://doi.org/10.1016/j.conbuildmat.2017.09.132>.
- [319] B.Ş. Şeker, M. Gökçe, K. Toklu, Investigation of the effect of silica fume and synthetic foam additive on cell structure in ultra-low density foam concrete, *Case Stud. Constr. Mater.* 16 (2022), <https://doi.org/10.1016/j.cscm.2022.e01062>.
- [320] S.S.S.A. Nedunuri, S.G. Sertse, S. Muhammad, Microstructural study of Portland cement partially replaced with fly ash, ground granulated blast furnace slag and silica fume as determined by pozzolanic activity, *Construct. Build. Mater.* 238 (2020), 117561, <https://doi.org/10.1016/j.conbuildmat.2019.117561>.
- [321] G. Adil, J.T. Kevern, D. Mann, Influence of silica fume on mechanical and durability of pervious concrete, *Construct. Build. Mater.* 247 (2020), 118453, <https://doi.org/10.1016/j.conbuildmat.2020.118453>.
- [322] J.S.A. Mohamed Amin, Abdullah M. Zeyad, Bassam A. Tayeh, Effect of ferrosilicon and silica fume on mechanical, durability, and microstructure characteristics of ultra high-performance concrete, *Construction and Building Materials, Construct. Build. Mater. J.* 320 (2022), <https://doi.org/10.1016/j.conbuildmat.2021.126233>.
- [323] W.S. Alaloul, M.A. Musarat, S. Haruna, K. Law, B.A. Tayeh, W. Rafiq, S. Ayub, Mechanical properties of silica fume modified high-volume fly ash rubberized self-compacting concrete, *Sustain. Times* (2021), <https://doi.org/10.3390/su13105571>.
- [324] H.Y. Leung, J. Kim, A. Nadeem, J. Jaganathan, M.P. Anwar, Sorptivity of self-compacting concrete containing fly ash and silica fume, *Construct. Build. Mater.* 113 (2016) 369–375, <https://doi.org/10.1016/j.conbuildmat.2016.03.071>.
- [325] Z. Wu, K.H. Khayat, C. Shi, Changes in rheology and mechanical properties of ultra-high performance concrete with silica fume content, *Cement Concr. Res.* 123 (2019), 105786, <https://doi.org/10.1016/j.cemconres.2019.105786>.
- [326] B.A. Tayeh, Utilization of waste Iron powder as fine aggregate in cement mortar, *J. Eng. Res. Technol.* 5 (2018) 22–27.
- [327] N.K. Amudhavalli, J. Mathew, Effect of silica fume on strength and durability parameters of concrete, *Int. J. Eng. Sci. Emerg. Technol.* 3 (2012) 2231–6604. <http://www.ijeset.com/media/4N5-IJESET0202520.pdf>.
- [328] A. Ghayoor Khan, B. Khan, E. Abdul Ghayoor khan, B. Khan, Effect of partial replacement of cement by mixture of glass powder and silica fume upon concrete strength, *Int. J. Eng. Work. Kambohwell Publ. Enterp.* 4 (2017) 124–135. www.kwpublisher.com.
- [329] J. Gražulytė, A. Vaitkus, O. Šernas, D. Čygas, Effect of silica fume on high-strength concrete performance, *World Congr. Civil, Struct. Environ. Eng.* (2020) 162, <https://doi.org/10.11159/icsect20.162>, 162.
- [330] R. Suryanita, H. Maizir, R. Zulapriansyah, Y. Subagiono, M.F. Arshad, The effect of silica fume admixture on the compressive strength of the cellular lightweight concrete, *Results Eng* 14 (2022), 100445, <https://doi.org/10.1016/j.rineng.2022.100445>.
- [331] T. Luo, C. Hua, F. Liu, Q. Sun, Y. Yi, X. Pan, Effect of adding solid waste silica fume as a cement paste replacement on the properties of fresh and hardened concrete, *Case Stud. Constr. Mater.* 16 (2022) 1–14, <https://doi.org/10.1016/j.cscm.2022.e01048>.
- [332] R. Garg, R. Garg, B. Chaudhary, S. Mohd, Arif, Strength and microstructural analysis of nano-silica based cement composites in presence of silica fume, *Mater. Today Proc.* 46 (2020) 6753–6756, <https://doi.org/10.1016/j.matpr.2021.04.291>.
- [333] Ö. Çakır, Ö.Ö. Sofyanlı, Influence of silica fume on mechanical and physical properties of recycled aggregate concrete, *HBRC J* 11 (2015) 157–166, <https://doi.org/10.1016/j.hbrj.2014.06.002>.
- [334] V. Bhikshma, K. Nitturkar, Y. Venkatesham, Investigations on mechanical properties of high strength silica fume concrete, *ASIAN J. Civ. Eng. (Building Housing)* 10 (2009) 335–346.