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Lightweight self-compacting concrete: A review

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ABSTRACT

Owing to the favorable properties of self-compacting concrete and light-weight aggregate concrete, the development of self-compacting concrete is an engineering excellence, although its application in civil engineering is limited due to a lack of in-depth research. The current review aimed to provide a detailed study of lightweight self-compacting concrete containing several types of natural and sustainable lightweight aggregates. As a primary constituent of lightweight self-compacting concrete, lightweight aggregates are mainly responsible for variation in strength and bulk density of concrete. The impact of different types of lightweight aggregate and other influential factors on workability, strength, and durability have been carefully discussed in this study which shows it is possible to develop lightweight self-compacting concrete even below the 1000 kg/m^3 density. In addition, lightweight self-compacting concrete shows excellent frost resistance. The study is a novel initiative to accumulate findings of lightweight self-compacting concrete for its broad acceptance, and future scope of work.

1. Introduction

We live now in a climate emergency, where the accumulation of CO$_2$ in the atmosphere is rising. The seriousness of this issue led to a series of global actions including the climate change conference (COP26) which took place in Glasgow-UK in November 2021. A study Pierrehumbert (2019) reported that "As long as we continue emitting any carbon dioxide, the world will continue to warm". Therefore, using pozzolanic materials in concrete can have notable impacts on CO$_2$ emission (Rudžionis et al., 2021). Ozawa and their co-workers developed SCC in 1986 which provided a paramount technological advancement in concrete construction (Maekawa, K., 1999; Ozawa et al., 1992). Developing SCC not only provided great quality of concrete, it significantly enhanced the productivity and working environment. The constituents of LWSCC are almost similar to LWAC but the composition and workability properties are different (Yu et al., 2013). To maintain the required fluidity, a higher volume of binders and admixtures are required; this enhancement in admixture and binder content might cause a rise in product cost giving rise to CO$_2$ emissions, and risk of shrinkage (Ranjbar et al., 2016; Sabet et al., 2013). In most of the studies, sustainable pozzolanic materials like fly ash, silica fume, and limestone powder are used as a partial replacement for cement that might have a significant role in the reduction of CO$_2$ emission. Using LWAC is not new in the concrete industry, and LWSCC is considered as an optimized product of SCC and LWAC (Yu et al., 2019). Several types of natural and artificial lightweight aggregates are used in LWSCC but mostly LWSCC is prepared with artificial aggregates, although the use of waste materials such as POC, EPS, COK, rubber, coconut shale, and plastic shows notable potential to be used as LWA. The use of recycled and waste materials in LWSCC might be a great step towards sustainability but it can change physical and mechanical characteristics according to their type and can affect the properties of LWSCC (Napolano et al., 2016).

The crushing strength of LWA is much lower than the conventional natural aggregates (Adhikary et al., 2022; Altalabani et al., 2020b) and concrete containing a higher volume of LWA might achieve lower compressive strength (Kurt et al., 2016a; Yim Wan et al., 2018). Using

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Nomenclature

ASR	Alkali-silica reaction
CA/FA	Coarse aggregate/fine aggregate
COK	Crushed olive kernel
EGA	Expanded glass aggregate
EPS	Expanded polystyrene
FA	Fly ash
FAA	Fly ash aggregates
GGBS	Ground granulated blast-furnace slag
ITZ	Interfacial transition zone
LECA	Lightweight expanded clay aggregate
LWA	Lightweight aggregates
LWAC	Lightweight aggregate concrete
LWASCC	Lightweight aggregate self-compacting concrete
LWSCC	Lightweight self-compacting concrete
MS	Micro silica
NA	Natural aggregate
NWA	Normal weight aggregates
NWC	Normal aggregates concrete
OPS	Oil palm shell
PFA	Pulverized fuel ash
POC	Palm oil clinker
PP	Polypropylene fiber
PVA	Polyvinyl acetate
RHA	Rice husk ash
SBR	Styrene-butadiene rubber
SCC	Self-compacting concrete
SCM	Supplementary cementitious materials
SF	Silica fume

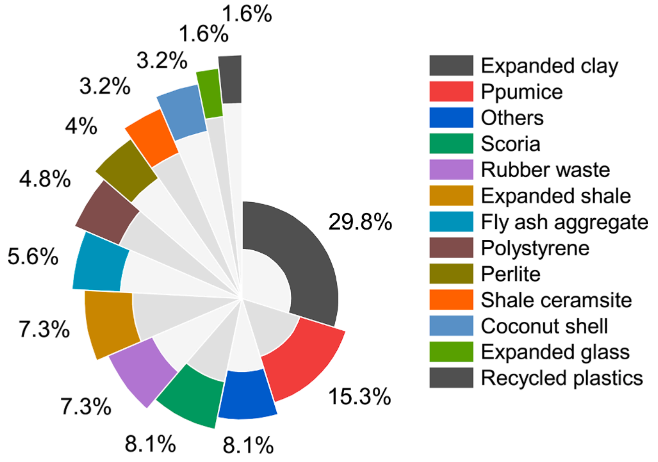

Figure 1. Share of different types of LWA in LWSCC published in last two decades.

very lightweight aggregate in concrete can cause segregation problem due to floating of the LWA (Juradin et al., 2012; Kwasny et al., 2012). This uneven distribution of LWAs', segregation, and poor self-compacting might hamper the structural performance and durability properties of concrete (Kwasny et al., 2012). To develop SCC below the density of 1200 kg/m^3, a high volume of LWA is required that can enhance the water absorption risks (Kurt et al., 2016b, 2016a). Such low-density concrete might be useful for thermal and sound insulation (Ting et al., 2019). The quality of ITZ of LWSCC prepared with different LWAs' might differ due to the variations in surface structure and adhesion properties. LECA, expanded glass, perlite and scoria added LWSCC shows good adhesion with cementitious materials (Barnat-Hunek et al., 2018; Duplan et al., 2014; Yashar and Behzad, 2021; Yu et al., 2013) while EPS, rubber, COK, and polymeric waste added LWSCC shows weaker ITZ (Angelin et al., 2020; Cheboub et al., 2020; da Silva et al., 2020; Ranjbar and Mousavi, 2015). So, the detailed study of different LWA added LWSCC might provide useful information to readers for their future research.

This study reviews the potential of different types of LWAs' in LWSCC production, providing detailed chemical and physical characteristics of different types of LWA. This is the first review study that presents the behavior of self-compacting concrete including several types of sustainable aggregates and different pre-treatments that can be applied to acquire strength and durability properties. The impact of different types, contents and, gradings of LWA on the workability and compressive strength of LWSCC have been described. Besides, other influential parameters such as water/binder, doses of fibers, nanofiber, and pozzolanic addition were considered to analyze the fresh and hardened properties of LWSCC. In every section, the reasons behind LWSCCs' improvement or deterioration have been addressed.

2. Sustainability, resources, and conservation perspective

Due to the technical myths and level of awareness, normal-weight concrete still plays a dominant role in the construction industry over lightweight concrete (Mousa et al., 2018). Mousa et al. (2018) stated that an adequate level of awareness and application of Kotter's model might be strategically helpful to guide stakeholders to make a sustainable change in construction culture. Because of NWC's dominance, about 9 billion tons of NA are consumed each year in the construction industry (Mehta and Monteiro, 2014). The depletion of NWA will lead to irreparable environmental damages and extensive destruction of ecosystems. Most of the lightweight aggregates are mainly prepared from waste materials, reuse and recycling of waste materials can lower the exploitation of non-renewable resources (Milutienė et al., 2012). The use of waste materials will also contribute to lowering the energy consumption through the industrial processes (Khankhaje et al., 2016). Oil palm shell, coconut shale, rubber waste, waste/recycled polystyrene, and recycled plastics are some successful examples of waste materials used in concrete production. Oil palm shale and coconut shale are agricultural solid waste materials (Mo et al., 2015b; Muthusamy and Kolandasamy, 2015), and dumping such materials in the environment can cause land pollution (Mo et al., 2015b; Peter et al., 2019).Mo et al. (2015a) reported that the use of oil palm shells in lightweight concrete combined with slag might cut CO$_2$ emissions by 50%. Similarly, around 1.5 billion waste tyres are generated every year, and most of them end up in landfills or open-air burning (Mashiri et al., 2015; Mohajerani et al., 2020). The burring of waste rubbers and landfilling might emit a substantial amount of toxic substance into the air and soil (Mohajerani et al., 2020). Medine et al. (2020) studied the LCA of rubber concrete and reported that rubberized concrete is cleaner, more environmentally friendly, produces fewer generated emissions, and requires less energy than conventional concrete. Similarly, the use of waste plastics and EPS as aggregate can be a potential alternative to lower environmental pollution. On the other hand, the production of expanded glass and fly ash aggregates might release some hazardous substances into the air (Adhikary et al., 2021a). Vossberg et al. (2014) reported that recycling waste glasses is more convenient and sustainable over landfilling which can avoid 0.39 (0.25–0.53) tonnes of CO$_2$ emission per tonne of glass. While LCA analysis suggests that the production of foamed glass from waste glass is more sustainable that have lower environmental emissions and saves a substantial amount of energy (Cozzarini et al., 2020; Gong et al., 2018). The use of such aggregates in concrete might be a

Table 1
physical properties of LWA.

LWA	Reference	Particle size, mm	Bulk Density, kg/m^3	Water absorptions, %	Compressive / crushing strength, MPa	Specific gravity
Expanded clay	(Nepomuceno et al., 2018)	4/12	637	14.2	–	–
	(Heiza et al., 2018)	2.36/16	667	18.2	–	1.08
	(Abdelaziz, 2010)	2.36/10	670	9.2	6.6	–
	(Altalabani et al., 2020b)	2–10	650±25	15±4%	>8	–
	(Yashar and Behzad, 2021)	Up to 12.5	658	13.2	–	1.126
	(N. Li et al., 2021)	4.75–15.0	–	13.3	2.8	–
Pumice	(Andiš-Šakć et al., 2009)	4–8 mm	480	20	–	–
	(Karthika et al., 2018)	8–10	460	2.8	–	1.84
	(Awoyera et al., 2020)	–	1305	2.59	–	2.33
	(Gonen and Yazicioglu, 2018)	0–4	843	18.10	–	–
		4–16	791	7.90	–	–
Scoria	(Yashar and Behzad, 2021)	Up to 12.5 mm	710	14.5	–	1.311
	(Naderi et al., 2018)	4.75–19	–	19.2	–	2.68
		0.075–4.75	–	2	–	1.56
	(Zhang et al., 2019)	0.075–13.2	–	–	–	–
Waste rubber	(Lv et al., 2020)	–	365 kg/m3	–	–	–
	(N. Li et al., 2021)	1.2–4	–	<1.0	–	–
Expanded shale	(Wu et al., 2021)	5–16	740 packing density	4.5	6	–
	(Zhu et al., 2016)	2.36–10	670	9.2	6.6	–
	(Liu et al., 2019)	2.36–16	855	6.4	7.5	–
	(Zhao et al., 2019)	5.20	827	6.98	7.4	–
Polystyrene	(Ranjbar and Mousavi, 2015)	2.36–4.75	13.6	–	–	0.025
	(N. Li et al., 2021)	1.5–4.5	10	<1.0	–	–
Perlite	(Yim Wan et al., 2018)	1.18–4.75	–	–	–	0.055–0.3
Shale ceramsite	(Li et al., 2017)	5–16	994	–	11.8	–
Coconut shale	(Poongodi and Murthi, 2020)	4.75–20	983	18	–	1.71
Expanded glass	(Yu et al., 2013)	4–0.1	310–810 dry particle density	2.81–7.8	–	–
Keramsite	(Nguyen et al., 2018)	5–10	710	13.0	6.5	2.65
Palm oil clinker	(Feen et al., 2017)	4.75–9.5	793	4.67	–	1.76

Table 2
Chemical compositions of LWA used in LWSCC.

Type of aggregates	Reference	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	SiO_3	K_2O	Na_2O	FeO	TiO_2	Mno	P_2O_5	LOI
Expanded clay	(Dolatabad et al., 2020)	66.05	16.57	7.10	2.46	1.99	–	0.03	2.69	0.69	–	0.78	0.09	0.21	–
	(Rampradheep and Sivaraja, 2016)	90.5	0.82	0.76	0.18	0.32	–	–	–	–	–	0.26	–	–	0.2
Pumice	(Mehrinejad Khotbehsara et al., 2017)	55.20	20.75	1.26	6.80	2.30	0.44	–	1.73	1.80	–	–	–	–	1.95
	(Kurt et al., 2015)	69.78	11.16	2.11	2.47	0.60	0.60	–	2.87	4.33	–	–	–	–	4.66
Scoria	(Dolatabad et al., 2020)	60.8	17	3.4	3.5	2.5	–	–	2.31	3.9		0.49	0.04	0.47	5.62
	(Ghanbari et al., 2020)	58.8	32.16	3.98	3.28	1.5	–	–	–	–	–	–	–	–	3.02
Perlite	(Dolatabad et al., 2020)	72.31	14.32	0.76	1.35	0.34	0.005	–	5.46	4.62		0.023	0.086	0.012	–
	(Aslani and Ma, 2018)	74	14	1	1.30	0.30	–	–	4	3		0.10	–	–	–

sustainable approach. Similarly the use of cold-bonded artificial lightweight aggregates in concrete possessed lower CO_2 emissions (Liu et al., 2022).

3. Properties of LWSCC

3.1. Physical properties of LWA

Literature studies indicate that several types of natural and artificial LWA have been used in the LWSCC. Recently published studies indicated that pumice, shale ceramsite, scoria, perlite, and coconut shale as commonly used natural LWAs' in LWSCC. While expanded clay, expanded shale, expanded glass, expanded polystyrene, waste/recycled plastic, waste/recycled rubber, and fly ash aggregates are commonly used artificial lightweight aggregates in LWSCC. **Figure 1** shows the share of LWA-based LWSCC studies published during the last two decades. Although several research studies have been conducted using natural and artificial lightweight aggregates to investigate the properties of LWSCC but still the correlations between the properties of LWA and performance characteristics of LWSCC are not entirely understood in various aspects. The physical properties of LWA and their characteristics highly depend on the type of lightweight aggregates. Strength, density, and water absorption are notable characteristics of LWA that varies with the type of LWA, and might have significant impact on the performance characteristics of concrete. **Table 1** indicates that expanded clay, pumice, scoria, expanded shale, and expanded glass have higher water absorption rates. While waste rubber, polystyrene, and plastic have negligible water absorption capacity. Water absorption of artificially prepared LWA mainly depends upon its cell size and inner pore structure, subject to the type and quantity of foaming agents used to prepare the LWA (Rashad, 2018). The cell size of LWA can lead to number of variations in strength and bulk density of LWA, its greater size can lead to a decrease in density and strength performance of LWSCC. Pumice, scoria, and perlite are naturally porous structured aggregates that

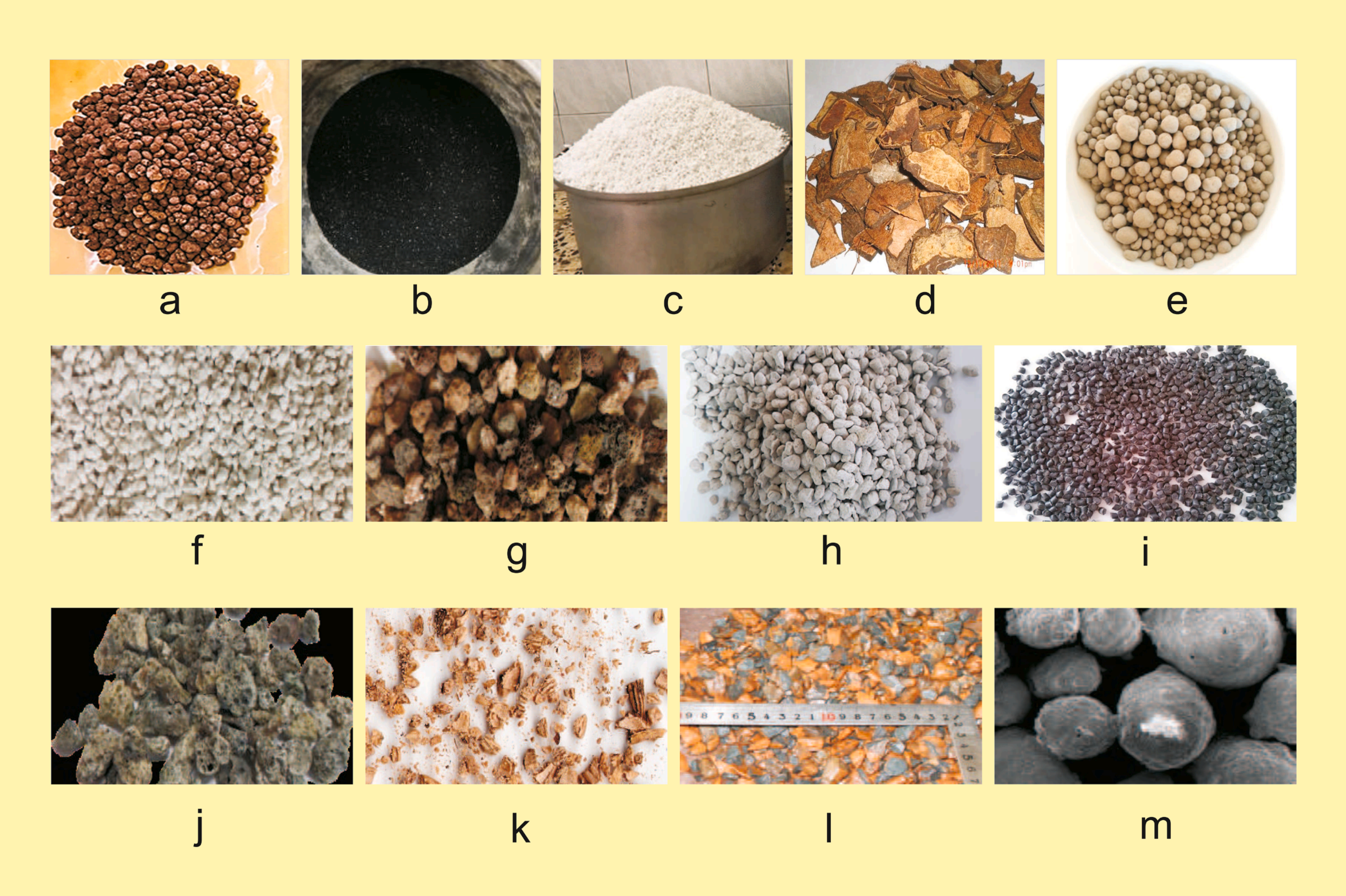

Figure 2. The shape of different types of LWA: a. expanded clay (Nahhab and Ketab, 2020); b. rubber (Hossain et al., 2020); c. EPS (Medher et al., 2021); d. coconut shell (Poongodi and Murthi, 2020); e. fly ash aggregate (Güneyisi et al., 2016); f. perlite (Dolatabad et al., 2020); g. scoria (Dolatabad et al., 2020); h. pumice (Agwa et al., 2020); i. recycled plastics (Faraj et al., 2021); j. POC (Feen et al., 2017) k. olive kernel shells (Cheboub et al., 2020); l. expanded shale (Wu et al., 2009); m. expanded glass (Spiesz et al., 2013).

generally increase the water absorption properties and decrease density and strength compared to conventional normal weight aggregates. The physical properties of different types of LWA are presented in **Table 1**.

3.2. *Chemical properties of LWA*

The chemical composition of LWA can play an influential role in the hardened properties of concrete. LWA containing silicon oxide can participate in the pozzolanic activity leading to alkali-silica reactions. **Table 2** shows that expanded clay, perlite, scoria, and pumice mainly consist of 55.20 to 90.5% silicon oxide elements of its entire constitution. Mo et al. (2021) conducted a comprehensive review on ASR and reported that LWA containing glassy phase and greater silica content like perlite and EGA can actively participate in pozzolanic reactions leading to ASR. In addition, expanded shale, expanded clay, and other artificial LWA containing pozzolanic materials promote the formation of hydration products. While recycled/waste rubber, recycled/waste plastic, polystyrene, coconut shale, and palm oil clinker might not have significant impacts on the pozzolanic reaction of cement-based composites (Ismail et al., 2020).

3.3. *Texture, size, and shape of LWA*

The performance characteristics of self-compacting concrete can be significantly influenced by the texture, shape, grading, maximum aggregate size, and morphology of aggregates. The packing of concrete and aggregate interlocking can be notably impacted by the shape and grading of aggregates. Most of the artificial lightweight aggregates such as expanded glass, expanded polystyrene, expanded clay, and fly ash aggregates are almost rounded in shape. While pumice, shale ceramsite, scoria, perlite, and coconut shale are flaky and angular in shape. **Figure 2** shows the shape of different types of LWA. Kwan and Mora (2001) reported that the shape parameter of aggregate plays an important role in the packing density of concrete. The packing of aggregate is directly impacted by the convexity of aggregates. The author also reported that filling up the concave area of aggregate is more strenuous, particularly containing almost similar size aggregates. Interlocking and shape factor of aggregate is the determining factor of required paste proportion to cover all particles. Cui et al. (2012) conducted a comparative study on lightweight concrete containing different shapes of lightweight aggregates and reported that the shape factor of lightweight aggregates might have a notable impact on the mechanical performance of concrete. An aggregate with a higher Shape Index indicates that it has a more angular shape and so has a greater impact on the mechanical characteristics of concrete. Karamloo et al. (2016a) studied the impact of maximum lightweight aggregate size on the fresh and mechanical properties of lightweight self-compacting concrete. Study results suggest that as the maximum aggregate size increases, the mechanical performance of the composite increases. While concrete samples prepared with a lower maximum aggregate size show comparatively lower slump flow. Gesoğlu et al. (2014) reported that incorporation of spherical-shaped LWA in SCC as a replacement of natural aggregates might improve the workability thus attributing to the ease in flow of the lightweight aggregate particles. **Table 3** shows that

Table 3
Fresh and mechanical properties of LWSCC.

Type of LWA	LWA		Cement, kg/m^3	Natural aggregates		Fine fillers	Additional Parameter	W/B	Filling ability		Passing ability		Density, kg/m^3	Compressive strength, MPa	References
	Size	Kg/m^3		Fine	Coarse				Slump, mm	T_{500}, sec.	V funnel, sec	L box			
Expanded clay	0–8	790.88–808.41	380–430	–	–	SF. FA, fillers	–	0.37–0.33	660–670	–	23–33	–	–	28.1–29.7	(Juradin et al., 2012)
	0–8	843–803	460	–	–	FA	–	0.46–0.43	795–805	–	13–12	0.94–0.97	1678–1703	59.4–64.4	(Iqbal et al., 2017)
	–	250	450–330	✓	–	Limestone powder	–	0.35–0.50	742–750	4.5–3.1	–	–	1887–1812	40.45–23.94	(Karamloo et al., 2016b)
	2–10	475–470	440–430	✓	–	Limestone powder	Microfiber	0.4	–	–	–	–	~1712 to ~1728	~61 to ~60.8	(Altalabani et al., 2020b)
	2–10	475–470	440	✓	–	Limestone powder	Microfiber and macro fiber	0.4	–	–	–	–	~1740 to ~1733	~57.6 to ~60.9	
	0–15	593–467	560	✓	–	FA,SF	–	0.42–0.44	660–670	2–3	8–12	–	1320–1242	44.7–40.3	(Corinaldesi and Moriconi, 2015)
	0–10	201–195	500	✓	✓	Limestone, SF	–	0.32 W/C	630–750	6–11	14–23	–	1850–1805	~28 to ~21	(Mazaheripour et al., 2011)
	0–8	830	465–485	–	–	FA	Steel fiber	0.46–0.48	790–630	5–9	–	–	1741–1746	67.8–59.74	(Iqbal et al., 2015)
Pumice	4–16	187–197	399–400	✓	–	Lime stone powder, FA	–	0.37–0.35	860–710	3.5–2	26.5–21	–	1786–1547	33.5–23.9	(Andiś-Sakć et al., 2009)
	0–16	1085–1071	440	–	–	FA	–	0.31	700–630	1.5–1.5	9–16	–	–	30.4 to ~37	(Gonen, 2018)
	–	50.05–200.2	424.4	✓	✓	GGBS	–	–	785–775	3–5	7–7	1–1	2440 to 1650	~42 to ~38	(Karthika et al., 2018)
	0–16	635–569	550	–	–	–	–	0.35–0.45	600–650	7–5	14–9	0.81–0.88	1037-1014	13.9 to 10.6	(Kurt et al., 2016b)
	0–16	731–759	440–330	–	–	Pumice powder	–	0.35–0.45	590–610	8–8	20–19	0.77–0.81	1011–840	13.2–10.6	
	0–16	705–0	375	✓	✓	FA,	–	0.30	650–800	8–2	21–8	0.77–0.93	1187–2156	19.9–53.3	
	0–16	753–0	375	✓	✓	Blast–Furnace Slag	–	0.30	645–770	9–3	26–9	0.77–0.93	1266–2278	21.3–65	
	0–16	645–753	440–330	–	–	Blast–Furnace Slag	–	0.35–0.45	620–720	6–4	17–12	0.77–0.83	1031–845	13.6–11.6	(Kurt et al., 2016a)
COK	0.125–4	–	650 g	✓	–	–	–	0.42	–	–	2.18–16.16	–	2274–1410	~54 to ~8	(Cheboub et al., 2020)
Oil Palm Shell	500µm – 10 mm	–	520–260	✓	–	FA	–	0.33–0.31	665–730	5.04–1.82	15–13	–	1832–1668	38.88–18.72	(Ting et al., 2020)
Shale ceramsite	5–16	613–602	358–359	✓	–	FA, SF	Steel fibers	0.34	700–600	2.6–9.8	20.2–36.3	–	–	~54 to ~60	(Li et al., 2021a)
	5–16	670.3–565.2	325.6–435.4	✓	–	FA, SF	mortar film thickness	0.35	~590 to ~630	12.4–1.3	–	–	~1940 to ~1870	~48 to ~50	(Li et al., 2017)
Scoria	1.5–12.5	420	405	✓	–	FA, limestone powder	SBR coating	0.38	705–750	3.2–2.8	9.5–9	0.84–0.86	1929–1690	~32 to ~37.5	(Yashar and Behzad, 2021)
	1.5–12.5	420	405	✓	–	FA, limestone powder	PVA coating	0.38	705–775	3.2–2.8	9.5–8.5	0.84–0.87	1929–1992	~32 to ~38.5	
	0.3 to 20	926–910	400–350	–	–	SF, mineral powder	–	0.45	690–790	3–2	5–4	0.81–0.97	1836–1809	~17.5 to ~17.1	(Naderi et al., 2018)
	0.3 to 20	929–911.2	450–393.75	–	–	SF, mineral powder	–	0.45	710–800	3–2	5–4	0.81–0.95	1872–1781	~17.4 to ~16.5	
	0.3 to 20	932–901.8	500–437.5	–	–	SF, mineral powder	–	0.45	700–800	3–2	4–4	0.93–0.96	1886 –1796	~22.5 to ~22.4	
	2.36–12.5	393	405	✓	–	zeolite	Glass fibers	0.4	747–683	3–3.5	8.1–9.9	0.93–0.84	1886–1890	~16.6 to ~16.2	(Ghanbari et al., 2020)
	2.36–12.5	393	380.7	✓	–	Nano silica, zeolite	Glass fibers	0.4	677–601	3.7–4.8	10.6–11.9	0.81–0.72	1893–1897	~21 to ~19.8	
Rubber	<4.75	0–155	425	✓	–	FA	Shale ceramsite	0.35	785–580	5.6–9.4	14.7–24.3	0.98–0.82	1921–1648	45.6–20.8	(Lv et al., 2020)

(*continued on next page*)

Table 3 (*continued*)

Type of LWA	LWA		Cement, kg/m^3	Natural aggregates		Fine fillers	Additional Parameter	W/B	Filling ability		Passing ability		Density, kg/m^3	Compressive strength, MPa	References
	Size	Kg/m^3		Fine	Coarse				Slump, mm	T$_{500}$, sec.	V funnel, sec	L box			
	2.36–9.5	48.12	180	✓	✓	FA, slag, SF	PP fibers	0.45	660–650	–	–	–	1916–1967	~12.6 to ~14.8	(Aslani and Kelin, 2018)
	2.36–9.5	48.12	180	✓	✓	FA, slag, SF	Steel fibers	0.45	660–610	–	–	–	1916–2013	~12.6 to ~17.6	
Plastic aggregates		1.5–4	0–78.5	369	703	–	FA	Expanded clay ceramsite	0.25	550 to ~770	~7.6 to ~6.1	–	–	~1600 to ~1400	~25 to ~22.6
	(Yang et al., 2015)														
	4–8	0–56	440	✓	✓	FA	–	0.35	750–670	3.8–3.5	19–22.5	0.89–0.85	–	78.1–61.6	(Faraj et al., 2021)
4–8	0–55.4	385	✓	✓	FA	SF	0.35	790–770	3.3–2.5	13.8–14.5	0.92–0.88	–	82.7–61.6		
Perlite	1.18–4.75	0–111	160	✓	–	FA, GBBS, SF	Crushed stone, 590–0 kg/m^3	0.45	680–590	1.96–195	–	–	2,310–1969	40.17–21.24	(Yim Wan et al., 2018)
	0–2	1.25–3.76	461	✓	✓	SF,	Steel fibers, basalt fibers	0.41	750–550	2–4.7	–	–	2172–1552	74.63–52.77	(Barnat-Hunek et al., 2018)
Fly ash aggregate	4–14	446	323	✓	–	FA	–	0.31	780	–	11.6	–	–	34	(Erdem, 2014)
	0.25–4	0–1022.5	440	✓	–	FA	–	0.40	24–25.5	–	10.34–6.84	–	2181.8–1792.5 (fresh)	~66 to ~22	(Güneyisi et al., 2015b)
	2–16	825.6–823.4	450–420	✓	–	FA	Nano silica, 0–30 kg/m^3	0.25	~700 to ~705	~3.7 to ~4.3	~24 to ~23.5	~0.81 to ~93	1959.4–1961.7 (fresh)	55 to 77.5	(Güneyisi et al., 2016)
		778.4–776.4	412.5–385	✓	–	FA	Nano silica, 0–30 kg/m^3	0.37	~710 to ~700	~1.1 to ~1.4	~7.6	~86 to ~97	1889.7–1892.1 (fresh)	44.0–65.0	
		796–795	337.5–315	✓	–	FA	Nano silica, 0–30 kg/m^3	0.50	~700 to ~711	~0.2 to ~0.5	~ 3.2 to ~5	~ 92 to ~1	1835.4–1838.4 (fresh)	30.5–49.0	
Coconut shale	–	552 kg/m^3	281	✓	✓	RHA, MS, FA	Banana Fibers 0.93–5.58 kg/m^3	0.48,	779–643		11.2–14.4	0.88–0.94	1802–1850	38.3–44.8	(Poongodi et al., 2020)
	Up to 12.5	234–700 kg/m^3	350	✓	✓	RHA	–	0.32	680–780		~12 to ~16	~0.81 to ~0.94	2060–1765	~28 to 19.33	(Poongodi and Murthi, 2021)
	Up to 12.5	234–700 kg/m^3	340	✓	✓	RHA, SF	–	0.34	700 to ~800	–	~11 to ~15	~0.83 to ~0.96	2005–1735	~32 to ~22	
Expanded glass	0.1 to 4	201.6–162.6 kg/m^3	425.3 to 423.5	✓	–	Microsand, Limestone powder	–	0.59–0.54	–	–	–	–	1280–1490	23.3–30.2	(Yu et al., 2013)
Polystyrene	2.36–12.5	0–30%	400	✓	✓	SF	–	0.44	645–680	–	6.2–13.6	0.92–0.83	2424–1712	45–17	(Madandoust et al., 2011)
	2.36–12.5	0–30%	388	✓	✓	SF	nano SiO2	0.44	620–660	–	8.2–15.7	0.89–0.81	2392–1701	52–18	
	2.36–12.5	2.92–2.86 kg/m^3	400	✓	–	SF	Waste Plastic Fiber, 0–17.5 kg/m^3	0.33	770–590	–	7–14	0.91–0.78	1694–1461	19.5–19.48	(Medher et al., 2021)
	2.36–12.5	1.92–2.8	400	✓	✓	Fine ceramic, ceramic powder	–	0.35	740–820	–	8–3	0.95–0.80	2000–1700	45–23	(Hilal et al., 2021)
Expanded shale	5–20	424–346	408	–	–	FA	Ceramsite sand	30	~730 to ~640	–	–	–	1542–1784	29.01–41.12	(Zhao et al., 2019)
	2.36–10	401–334	330	✓	–	PFA	–	0.40	~850 to ~810	–	–	~0.84 to ~0.93	–	~40.8 to ~42.5	(Zhu et al., 2016)
	2.36–10	401–334	330	–	–	PFA	Manufactured sand	0.40	~745 to ~700	–	–	~0.82 to ~0.68	–	~39.6 to ~41	
	2.36–10	401–334	330	–	–	PFA	Expanded shale sand	0.40	~725 to ~695	–	–	~0.78 to ~0.64	–	~35.8 to ~38.9	
	2.36–16	450	395	✓	–	FA, SF	Steel fibers and Polypropylene fibers	0.33 to 0.30	690 to 645	–	11.2–19.3	0.85 to 0.98	1817–1894	52.8 to 56.7	(Liu et al., 2019)

up to 20 mm size LWA was used in the LWSCC while most of the LWSCC were prepared with 12.5 to 16 mm maximum size LWAs'; although up to 20 mm maximum size aggregates were used in the preparation of LWSCC, but its concentration was very less in the concrete matrix. Besides, effectively graded LWA can lower the void content and provide superlative flowability and strength. The surface texture of LWA is a salient factor having a remarkable impact on the adhesion of concrete where the surface texture of LWA mainly depends on its type. The rough surface texture of LWA might increase adhesion between binding materials and aggregates, while the smooth surface texture of LWA leads to a decrease in adhesion.

3.4. *Bulk density*

The bulk density of LWA is a key factor in measuring the requisite volume of binding materials, and volume of voids in the concrete mix (Nadesan and Dinakar, 2017). It is also an important parameter used to develop SCC mix design by volume proportioning methods. The bulk density of different LWAs' vary according to their type and source. **Table 1** shows the bulk density of LWA can vary from 10-1305 kg/m^3, depending upon the type of LWA involved. Literature studies indicate that the bulk density of LWA of the same type of aggregate can also vary according to the size, and porosity of the aggregate (Ozguven and Gunduz, 2012). ASTM C330 - 05 (2005) suggested that LWA with the loose density range of 880–1120 kg/m^3 is preferable for structural applications. According to ACI-213R-14 (2014) LWAC with the density range, 1350-1900 kg/m^3 having compressive strength $\geq$17 is also permissible for structural use. However, lightweight density generally hinders the design of LWSCC where a high concentration of very lightweight aggregate such as expanded glass and expanded polystyrene is used. The bulk density of LWA and its concentration in concrete mixture decide the possible density of LWSCC. Although hardened properties of LWSCC with similar density prepared from different LWAs' can differ attributed to the properties of LWA and mixing composition of the concrete mix.

3.5. *Specific gravity*

The specific gravity of aggregate is a crucial factor for determining void content, required binding material, and the design of SCC based on weight-to-volume proportioning methods. The fresh and hardened properties of LWSCC such as flowability and density can be impacted by the variations in specific gravity of aggregates (Ting et al., 2019). The specific gravity of natural conventional coarse aggregate is about 2.4–2.9, while **Table 1** shows the specific gravity of LWA varies between 0.025-2.68. The variations in specific gravity can be associated with the sources of LWA and manufacturing methods. Ting et al. (2019) reported that LWA having <2.0 specific gravity is mainly used to prepare below 1920 kg/m^3 density LWSCC.

3.6. *Mechanical properties of LWA*

Mechanical properties of concrete are one of the major hardened properties that can be significantly impacted by the strength of LWA. **Table 1** shows the crushing strength of different types of LWA varying up to 11.8 MPa depending on the type of LWA. However, most of the LWSCC studies did not reveal the crushing strength of lightweight aggregates, but evidently, the crushing strength of LWA is much lower than the NWA. The fluctuations in the strength of different LWAs can be attributed to the source of LWA and its production mechanism. The strength of artificially prepared LWA such as expanded glass and expanded clay can largely depend upon the sintering temperature, size, pore size, and total porosity of the aggregates (Ozguven and Gunduz, 2012). **Table 3** indicates almost a similar density LWSCC prepared with different types of LWAs', however, shows a significant difference in strength due to variations in the strength of aggregates and mixing composition of the concrete mix.

3.7. *Water absorptions of LWA*

The water absorption capacity of LWA is a crucial factor that must be considered during concrete mix design, aggregate with higher water absorption capacity can impact the water/binder ratio (Liu et al., 2011). However, to overcome this problem pre-wetting of LWA can have significant positive impacts (Nguyen et al., 2018). **Table 1** suggested that most lightweight aggregates have higher water absorption capacity than conventional aggregates and are subject to higher open porosity leading to an increase in water absorption capacity. As revealed from **Table 1** expanded clay, pumice, scoria, and coconut shale have comparatively higher water absorption capacity than the other LWAs'. Literature studies indicate that similar types of aggregates can also have variations in water absorption capacity that can be attributed to their degree of porosity and pore structure. However, some LWAs' such as expanded polystyrene, plastic, rubber, and glass aggregate have negligible water absorption capacity. The use of LWA with a higher water absorption rate increases the water absorption of LWSCC; higher water absorption of concrete might have an impact on the durability of concrete by allowing harmful ions to enter the concrete. However, porous structured LWA can soak water during the mixing process and provide internal curing (Rampradheep and Sivaraja, 2016; Shafigh et al., 2012; Yang and Wang, 2017). Notably, it was observed that internal curing provided by LWA can reduce plastic shrinkage, increase strength, and provide complete hydration of cement (Rampradheep and Sivaraja, 2016; Ting et al., 2019; Yang and Wang, 2017).

4. Fresh properties of LWSCC

Development of LWSCC concrete mix design is comparatively more difficult than the conventional SCC, till now there are no standards in practice for LWSCC mix design. Most of the LWA are irregular-shaped and porous structured which leads to lower workability compared to NWA. Due to the higher water absorption of porous structured LWA, workability of LWSCC is generally compromised. The proper estimation of water content considering the water absorption properties or pre-wetting the LWA before mixing is a common technique in practice to overcome this problem (Domagała, 2015; Nguyen et al., 2018). Literature studies also indicate that water absorption of LWA can vary according to its type and size; proper amount of water calculation is a prime factor to protect the LWSCC from segregation and bleeding (Juradin et al., 2012). Due to the lightweight density of LWA, LWSCC can face segregation and improper self-compaction leading to the floating LWA (Kwasny et al., 2012). It becomes essential to achieve proper mix design by mixing and trial method, in addition, an increase in binding paste concentration can help to achieve target workability. The fresh properties of LWSCC containing different LWA and their mixing composition are presented in **Table 3**. Literature studies suggested that the workability of LWSCC not only depends on the type of LWA but is also impacted by several parameters discussed below.

4.1. *Effects of type of aggregate*

Yashar and Behzad (2021) conducted a comparative study of LWSCC prepared with scoria and expanded clay and reported that expanded clay-based LWSCC performed better than scoria-based LWSCC in terms of filling ability and passing ability. Dolatabad et al. (2020) investigated the fresh properties of LWSCC containing perlite, scoria, and expanded clay. It has been observed that at similar mixing composition the workability of LWSCC differ depending on the type of LWA; Soria-based LWSCC shows the lowest V funnel time. N. Li et al. (2021) reported that expanded clay-based LWSCC show greater flowability and passing ability compared to rubber and EPS-based LWSCC. This inconsistency in fresh properties of various LWA-based LWSCC suggested that the workability of LWSCC can be significantly impacted by the type of LWA used in the concrete mix. These variations in fresh properties can be attributed to the differences in the physical properties of aggregates such as shape, surface texture, density, and water absorption.

4.2. Effects of concentration of aggregates

Depending upon the type of LWA, the concentration of aggregate is another important factor in controlling the fresh properties of LWSCC. The fresh properties of LWSCC greatly depend upon the mixing composition, chemical, and pozzolanic admixtures. However, literature studies indicate that almost at identical mixing compositions, the concentration of LWA also impact the fresh properties of LWSCC. Poongodi and his co-workers (Muthusamy and Kolandasamy, 2015; Poongodi and Murthi, 2021) studied the impact of coconut shale aggregates on the fresh properties of LWSCC and reported that the flowability of LWSCC increased by the increase in the content of coconut shale aggregate as a replacement to natural aggregate. Authors reported almost a 14% increase in a slump by incorporating coconut shale aggregate as a 100% replacement of natural coarse aggregates (Poongodi and Murthi, 2021). Kanadasan and Razak reported an increase in flowability, a decrease in T_{50} and V funnel time with the increase of POC aggregate in the LWSCC (Kanadasan and Abdul Razak, 2015). Authors observed an almost 8% increase in slump flow and a 34% and 40% decrease in T_{500} and V funnel times, incorporating POC as a 100% replacement of gravel. A similar increase in flowability by the increase in the concentration of polymeric waste (da Silva et al., 2020), Ponza aggregates (Almawla et al., 2019), cold bonded fly ash aggregates (Güneyisi et al., 2015b) was also observed. Some studies show the flowability of pumice aggregate-based LWSCC increased till a certain replacement volume of pumice and afterward starts decreasing (Gonen and Yazicioglu, 2018; Karthika et al., 2018; Mehrinejad Khotbehsara et al., 2017). While the use of some aggregates like rubber (Li et al., 2021; Lv et al., 2019a), perlite (Dolatabad et al., 2020; Yim Wan et al., 2018), scoria (Aslani and Ma, 2018; Dolatabad et al., 2020; Yim Wan et al., 2018) shows a decrease in flowability with the increase in their concentrations (Aslani and Ma, 2018). According to Lv et al. (2019a) using rubber particles as a 50% replacement to fine aggregate reduces slump flow from 785 mm to 580 mm and increases T_{500} time from 5.6 to 9.4 seconds. A decline in the workability of rubberized concrete might be attributed to the irregular shape and rough surface of rubber particles. Yim Wan et al. (2018) reported that the incorporation of perlite as a 100% replacement of natural fine aggregates lowers the slump flow by 21.3%. Similarly, authors also reported that incorporation of scoria as a 100% replacement of natural coarse aggregates lowers the slump flow by 16%. The decrease in workability can be attributed to the higher water absorption capacity of scoria and perlite. However, the authors suggested that pre-wetting of such aggregates might help to improve their workability. This comprehensive review suggests that the fluctuations in flowability of different LWA-based LWSCC can be attributed to the physical properties of aggregates and mixing compositions.

4.3. Effects of size of aggregate and packing density

The size and grading of LWA is the foremost factor for the mix design of LWSCC that can significantly impact the packing density and fresh properties of LWSCC.Mazaheripour et al. (2011) reported that the flowability of expanded clay-based LWSCC increased when a combination of fine and coarse expanded clay was used as a replacement to natural fine aggregates. This increase in flowability could be due to the increase in viscosity, however, an increase in viscosity also leads to an increase in V funnel and T_{500} time. Omar et al. (2020) analyzed the C/F ratios on the workability of LWSCC of slate aggregate-based LWSCC. Study results reported that flowability of LWSCC decreased and T_{500} time increased by the increase in C/F ratio. Some studies Lotfy et al., (2016) and Shi and Wu, (2005) reported that the use of fine LWA can eliminate voids between aggregates and show better packing density leading to greater segregation resistance and higher flowability by allowing excess paste in LWSCC.

4.4. Effects of binding materials and fine content

Li et al. (2017) reported the importance of packing and mortar film thickness on the workability of shale ceramsite-based LWSCC. Study results reported that a higher amount of cement and fine content increases the film thickness which efficiently improves the workability of LWSCC due to the reduction in friction between aggregates. The study observed almost an increase of 25% in slump flow of LWSCC by increasing mortar film thickness from 1.4 to 2.0 mm. However, above 2.0 mortar film thickness, authors reported a decline in slump flow. While V funnel and T_{500} time was decreasing with the increase in mortar film thickness of the LWSCC. Kanadasan and Razak (2014) also reported that the increase in powder or fine aggregate content increases the paste volume of the POC-based LWSCC which significantly improved the workability of concrete. Almost 8% slump flow of LWSCC increased by increasing paste volume from 0.41 to 0.52 m^3/m, while T_{500} and V funnel time of the composite decreased from 14 to 6 seconds and 5 to 2 seconds, respectively. Floyd et al. (2015) reported that a higher concentration of cement can contribute to improving the visual stability of LWSCC.

4.5. Effects of supplementary pozzolanic materials

Supplementary cementitious material plays an important role in controlling the fresh and hardened properties of concrete. The effectiveness of supplementary cementitious materials might depend on the type and concentration of SCM. Naderi et al. (2018) studied the impact of SF as a partial replacement to cement in scoria-based LWSCC and reported improved flowability, blocking ratio, slump, and V funnel time. The effectiveness of SF was increased by the increased concentration of SF in the concrete mixture. By incorporating 12.5% SF as a replacement to cement, the authors reported an almost 14.5% increase in slump flow. Several researchers also reported similar improvement in workability by the addition of SF to LWSCC prepared with different type of LWAs' such as coconut shale (Poongodi and Murthi, 2021) and, plastic aggregates (Faraj et al., 2021). This improved workability effect of LWSCC can be attributed to the lubrication effect provided by silica fume that might have released entrapped water between small particles thus resulting in an enhancement in flowability (Mehta and Ashish, 2019). Ting et al. (2020) studied the impact of fly ash as a partial replacement to cement on the workability of oil palm shell-based LWSCC. Study results indicate that incorporation of FA significantly improved the filling and passing ability of LWSCC. It was observed that replacing 50% of cement by FA increased the slump flow spread from 660 mm to 730 mm and T_{500} was reduced from 5.04 seconds to 1.82 seconds. Similarly, Güneyisi et al. (2012) also confirmed the role of FA in workability enhancement. The improvement in workability of LWSCC by the addition of fly ash can be attributed to the dilution effect that diminishes the flocculation of the cement particles. Besides, spherical-shaped FA particles provide ball-bearing effects by facilitating the movement of neighbouring particles (Hemalatha and Ramaswamy, 2017). Agwa et al. (2020) reported a comparative study of LWSCC prepared with rice straw ash and cotton stalk ash as a replacement for cement. Study results indicate that relative to the control sample, the workability of LWSCC containing cotton stalk ash and rice straw ash was reduced. The authors observed a nearly 20% and 13% decrease in slump flow, a 133% and 66.6% increase in T_{500} time, and a 97.2% and 61.6% increase in V funnel flow time by replacing 20% of cement with rice straw ash and cotton stalk ash, respectively. This reduction in workability can be attributed to the high specific surface area of cotton stalk ash and rice straw ash. This comprehensive study indicates that the workability of LWSCC can be significantly controlled by the use of proper type and doses of supplementary cementitious materials.

4.6. Effects of water cement ratio and superplasticizer

The fresh properties of LWSCC largely depend on the water/binder ratio and doses of superplasticizer. Güneyisi et al. (2016) prepared a series of fly ash aggregate-based LWSCC samples with different water/binder ratios. Study results reported that the increase in water/binder ratio significantly improved the passing and filling ability. A similar improvement in the workability of LWSCC was observed by several authors (Kurt et al., 2015; Lotfy et al., 2015; Sonebi et al., 2007). Lotfy et al. (2015) and confirmed that the demand for superplasticizers might increase with higher binder content to maintain the workability of LWSCC. Besides, the use of ultrafine particles in concrete can increase the demand for water, in that case, higher water or an increase in superplasticizer dose is required to achieve the desired workability The increase in superplasticizer content with water/binder ratio was observed to be effective to achieve higher workability. Similarly, improved workability of LWSCC by enhancing superplasticizer doses was reported by Floyd et al. (2015).

4.7. Effects of pre-treatment of aggregates

Yashar and Behzad (2021) coated scoria and expanded clay with SBR and PVR latex and used it in the LWSCC production. It was reported that the slump of LWSCC improved by 2%–10% due to a reduction in water absorption of aggregates provided with hydrophobic latex coatings. The improving slump of LWSCC was more significant with higher latex coating layers. Besides polymer membrane layers decreases the frictional forces leading to a decrease in flow time and blocking resistance of LWSCC. Similarly, Güneyisi et al. (2016) studied a comparative study of LWSCC prepared with untreated FAA and treated FAA by water glass. It was suggested that LWSCC showed better workability prepared with treated FAA than the untreated FAA aggregates. Due to the hydrophobic water glass coating, the water absorption of FAA, and cohesion forces were reduced leading to an improvement in slump flow and a decrease in flow time and blocking resistance of LWSCC. So, from this literature, it can be concluded that hydrophobic coating on LWA can slightly lower the water demand and improve the workability of concrete.

4.8. Effects of type and forms of fibers

In recent years, several experimental studies have been conducted to understand the impacts of different doses and types of fibers of the LWSCC. Altalabani et al. (2020a) studied the impact of micro and macro polypropylene (macro-PP) fibers on the expanded clay-based LWSCC. It was observed that incorporation of both micro and macro PP fibers significantly reduced the slump of LWSCC. By incorporating micro and macro fibers into the LWSCC, the authors reported a nearly 19% and 5.1% decrease in slump flow, respectively. The reduction rate in workability was more significant for micro PP fiber additions than the macro-PP fibers. Aslani and Kelin (2018) and Liu et al. (2019) used PP fibers in scoria and expanded shale-based LWSCC and reported a decrease in workability with the increase in PP fibers concentrations. Li et al. (2021b) used steel fibers in LWSCC and observed that the addition of both long and micro steel fibers inhibits the passing and filling ability but enhances the segregation resistance. The slump flow of concrete incorporating 1% long and micro steel fibers was reduced to 7.1% and 14%, and T_{500} time increased by 220% and 400%, respectively. Several research outputs show a similar reduction in the slump and flow time of LWSCC prepared with steel fibers (Grabois et al., 2016; Nahhab and Ketab, 2020; Zhao et al., 2019), banana fibers (Poongodi and Murthi, 2020), glass fibers (Ghanbari et al., 2020), waste plastic fibers (Medher et al., 2021). Probably the addition of fibers in the LWSCC creates a three-dimensional web and provides internal resistance leading to inhibiting the flowability.

4.9. Effects of nanomaterials

Dolatabad et al. (2020) studied the impacts of nano-SiO_2, nano-TiO_2, and nano-Al_2O_3 on the fresh properties of LWSCC. The slump flow was reduced to 700 mm from 750 mm by incorporating 4% nano-SiO_2, nano-TiO_2, and 2% nano-Al_2O_3. A similar decline in flowability of LWSCC incorporating nano-silica was reported by several authors (Ghanbari et al., 2020; Madandoust et al., 2011). The reduction in fluidity can be attributed to water absorption of nano-SiO^2 during the mixing process and increased packing density and internal frictions. Afzali Naniz and Mazloom (2018) suggested that the incorporation of colloidal nano-silica lowers the slump flow and increases the flow time, but it can provide better bleeding and segregation resistance.

5. Compressive strength of LWSCC

The compression strength of concrete is one of the desirable properties that have a significant impact on the structural performance of the composite. The compressive strength can be relatable with desired density, decrease in density contributes in decreasing the strength of the concrete. The compressive strength of LWSCC containing different LWA and their mixing composition are presented in **Table 3**. There are several other aspects that might impact the compressive strength of LWSCC as discussed below.

5.1. Effects of type of aggregate and its concentration

The strength of LWA is much lower than the conventional aggregates and utilization of LWA in LWSCC can have a significant impact on the compressive strength. There are several types of LWA used in LWSCC production, where the density and strength of LWSCC can differ due to inconsistency in their physical properties (Aslani and Ma, 2018; Yashar and Behzad, 2021; Yim Wan et al., 2018). Yashar and Behzad (2021) indicate that due to the variation in characteristics of LWAs' at similar mixing compositions, concrete prepared with low strength LWA might achieve low compressive strength. The authors conducted a comparative study of LECA and scoria-based LWSCC prepared at similar mixing composition where LECA-based LWSCC achieved comparatively lower compressive strength. A similar inconsistency in compressive strength was observed by Dolatabad et al. (2020) with almost similar mixing composition. These studies reveal that the use of highly porous LWAs such as LECA, pumice, expanded glass, and polystyrene might notably decrease the compressive strength of concrete. A higher decline in compressive strength was observed with a higher concentration of LWA in the concrete mix. Some lightweight aggregates such as rubber and expanded polystyrene have weaker adhesion with cementitious materials. The inclusion of this type of LWA at higher concentrations can cause a decline in strength (Aslani and Kelin, 2018; Madandoust et al., 2011). However, generally used LWAs' satisfy the CEB/RILEM requirements to be used as aggregate in structural concrete. But, the inclusion of rubber, pumice and COK at higher concentrations might fail to achieve the required strength and further research is required for their use in structural concrete (Aslani and Kelin, 2018; Cheboub et al., 2020; Kurt et al., 2016b).

5.2. Effects of size of aggregate and packing density

The size of aggregates might show some notable impact on the strength of concrete; during the mix design, the particle size factor should be considered to achieve optimum strength. Lotfy et al. (2015) reported that the use of a low volume of larger size LWA achieves greater compressive strength. However, according to Nahhab and Ketab (2020) the LWSCC prepared with smaller size LWA (LECA) achieves comparatively greater compressive strength than the LWSCC prepared with larger size LWA. Usually, smaller size LWA has greater strength than the larger size LWA, leading to enhancement in strength. Besides, mostly larger size artificially prepared LWA contains large pores leading to weakening strength. A similar enhancement in the strength of concrete using smaller size LWA was observed in several studies (Miled et al., 2007). So, it can be concluded that in terms of strength characteristics of LWSCC, the use of smaller size LWA might provide beneficial impacts.

5.3. Effects of binding materials and fine content

The use of an optimum level of fine content and binding materials in LWSCC might provide maximum strength gain. The greater amount of fine particle material might enhance the mortar film thickness of concrete. Li et al. (2017) conducted experimental studies to investigate the importance of packing and mortar film thickness on the strength of LWSCC. It was observed that on 28 days of hydration, a concrete sample with 1.8 mortar film thickness gains maximum strength. By increasing mortar film thickness from 1.4 to 1.8 mm, the authors observed a 21.2% increase in compressive strength. However, the authors also reported that the compressive strength of the concrete samples started to decrease as film thickness increased above 1.8 mm. Similarly, Kanadasan and Razak (2014) reported that an increase in powder or fine aggregate content enhances the overall paste volume that positively impacted the workability, but it negatively affected the strength gain of LWSCC. The compressive strength of LWSCC decreases by the enhancement in paste volume. While Floyd et al. (2015) suggested that the use of a greater amount of cement is required to maintain adequate viscosity for greater workability and higher early strength. However excess amount of cement content might lead to crack and shrinkage and impact the durability characteristics of concrete. From the literature, it can be concluded that the use of a higher amount of fine particles can improve the workability but it can negatively impact the strength gain of LWSCC. Hence selection of an optimum level of fine particles might provide the required workability and strength.

5.4. Effects of supplementary pozzolanic materials

Nowadays various types of natural and industry eject pozzolanic materials are used in SCC for the improvement of fresh and hardened properties. The degree of pozzolanic reactions and the impact of those pozzolanic materials might differ according to their type and characteristics. Although SF, FA is the most frequently used pozzolan due to their easy availability. Naderi et al. (2018) used SF in scoria-based LWSCC and reported that the use of silica fume improved the compressive strength of concrete. The addition of 5% SF as a replacement to cement provided optimum compressive strength on 28 and 56 days of hydration. The incorporation of 5% SF resulted in a nearly 6% increase in compressive strength. The improvement in compressive strength was more significant with higher content of cement in the concrete mixture. Similarly, by the inclusion of SF, Faraj et al. (2021) reported the enhancement in compressive strength of plastic aggregate added LWSCC. The use of a small amount of SF accelerates the hydration thus improving the strength development, while a greater amount of SF delays the hydration due to the formation of hydrated calcium silicates and calcium hydroxide (Mehta and Ashish, 2019). However, SF added concrete generally gains greater strength at a longer hydration time, but the use of more than 20% SF is not recommended in the concrete. Ting et al. (2020) studied the impact of FA on the properties of LWSCC and reported that the addition of FA positively impacted the workability, but declines the compressive strength of concrete. It was also observed that with the rise in FA content the declining rate in compressive strength was more significant. Authors reported an almost 51.8% decline in compressive strength by incorporating 50% FA as a replacement for cement. Basically, the addition of FA in concrete delays the hydration, and concrete achieves lower strength on 28 days. However, Agwa et al. (2020) suggested that 10% doses of rice straw ash and cotton stalk ash might effectively enhance the strength of LWSCC. Authors reported an almost 13.6% and 31.8% increase in compressive strength by incorporating 10% rice straw ash and cotton stalk ash into LWSCC. However, when the pozzolanic addition is more than 10%, the effectiveness of the addition drops, and the compressive strength of the concrete decreases. From the literature studies, it can be concluded that the addition of pozzolans like SF and FA might have greater impacts on fresh properties of LWSCC but in terms of compressive strength, it shows similar impacts like in conventional concrete.

5.5. Effects of water-cement ratio and superplasticizer

Like normal weight concrete, the water-cement ratio has a significant impact on the properties of LWSCC. The use of untreated porous aggregates in LWSCC might enhance the requirement of water or doses of superplasticizer to maintain workability. But like conventional SCC and normal-weight concrete, the use of a greater amount of water decline the strength gain of LWSCC. Güneyisi et al. (2016) reported that a higher water/binder ratio significantly declines the compressive strength of LWSCC, however small doses of nano-silica at higher w/b were found to be effective to improve the strength of LWSCC. A similar decrease in strength of LWSCC with higher water content was observed by Lotfy et al. (2015). Generally, LWAC is more porous than conventional concrete resulting in its lower strength gain. Along with it, higher water/binder ratio creates a greater amount of pores due to the evaporation of free water, and concrete gains comparatively lower strength due to a higher porosity.

5.6. Effects of addition of natural aggregate

In terms of strength of concrete use of conventional normal weight aggregates combined with LWA might gain higher strength. Although the use of conventional aggregate will enhance the final density and thermal conductivity. Ranjbar and Mousavi (2015) used combinations of EPS and natural aggregates to produce LWSCC and reported that a low volume of EPS with high content of NA shows greater strength gains. (Kaffetzakis and Papanicolaou, 2016) conducted an experimental study on pumice-based LWSCC and observed that river sand added LWSCC gains greater strength over pumice sand added LWSCC. Conventional NA has greater strength than LWA and incorporation of NA combinedly with LWA helps to gain higher strength, these phenomena substantiate the fundamental knowledge of concrete science.

5.7. Effects of pre-treatment of aggregates

In recent years, pre-treatment of LWA is becoming popular to improve the fresh and hardened properties of concrete. Vahabi et al. (2021) used SBR and PVA latex coated scoria and LECA for the production of LWSCC. It was observed that latex coating on LWA significantly improved the fresh and mechanical properties of LWSCC. Providing another layer on LWA improved almost 21% and 13.5% compressive strength for scoria and LECA-based LWSCC. Assaad and El Mir (2020) reveal that the use of SBR latex improved the bond strength by promoting the formation of monolithic interlayer bonding and hindering the microcrack propagation. Güneyisi et al. (2016, 2015a) suggested that the use of water glass as a pre-treatment agent of LWA (cold bonded fly ash aggregate) might effectively improve the strength of LWSCC. The effectiveness of the pre-treatment is more significant when nano-silica and lower water/binder were used. The author reported an enhancement of almost 32% to 44% in compressive strength of LWSCC by using water glass as a pre-treatment agent. Probably, use of water glass makes LWA denser and harder leading to the enhancement of compressive strength. Water glass is also a lightweight material, and it does not have much impact on enhancing the density of aggregates. So, it can be concluded that the use of these pre-treatment methods can be very beneficial to enhance the strength of LWA, especially for porous structured LWAs such as EGA, and LECA.

Table 4
Durability properties of LWSCC.

References	LWA type	LWA quantity, kg/m^3	W/B	Water absorption, %	Capillary water absorption	Drying shrinkage	Electrical resistivity	Chloride profile	Freeze thaw resistance
(Spiesz et al., 2013)	EGA	162.6–201.6	0.26–0.35	–	0.0068–0.0138 (g/mm^2)	–	32.2 to 34.1 Ωm	9.08–15.38 (10^{12}m^2/s) Chloride diffusion	21.4–23.9 g/m^2 surface scaling
(Ranjbar and Mousavi, 2015)	EPS	22.5–30%	0.44	~4.7 to ~6.8	–	–	~10 to ~12.5 kΩ–cm	Till 15% EPS shows less than threshold value of chloride profile at 2.5 cm covering depth	–
(Feen et al., 2017)	POC	440	0.38	~4.3	–	–	–	–	–
(Ting et al., 2020)	OPS	455	0.31–0.33	6.10–7.33	–	–	–	–	–
(Barnat-Hunek et al., 2018)	Perlite	6.25–18.76	0.41	10.64–15.57	–	–	–	–	0.03–7.88% mass loss after 50 cycles
(Kurt et al., 2015)	Pumice	140–705	0.30–0.45	8.58–24.51	–	–	–	–	–
(Gonen and Yazicioglu, 2018)	Pumice	0–30%	–	–	1.45–2.69 cm/s0.5	–	–	–	–
(Ghanbari et al., 2020)	scoria	393	0.40	~2.75 to ~5	–	–	~45 to ~160 kΩ–cm	–	–
(Yashar and Behzad, 2021)	Scoria	420	0.38	4.5–5.56	–	~425 to ~500 × 10^{-6}	–	–	–
	LECA			3.96–5.51		295 to 395 × 10^{-6}			
(Afzali Naniz and Mazloom, 2018)	LECA	270	0.35	–	–	–	55–211 Ωm	–	–
			0.45				43–202 Ωm		
(Corinaldesi and Moriconi, 2015)	LECA	370–593	0.42–0.44	–	–	~–.060 to ~–0.310 mm/m	–	–	–
(Nahhab and Ketab, 2020)	LECA	93–186	0.25	–	–	280 to 445 × 10^{-6}	–	–	–
(Shi and Wu, 2005)	Expanded shale	546	0.34	–	–	~0.64 to ~0.82 %	–	3.46–7.39	Exhibits excellent frost resistance
(Lv et al., 2019b)	Rubber	31–155	0.39	–	–	335 to 384 × 10^{-6}	–	–	–
(Güneyisi et al., 2015c)	Cold bonded fly ash	657–688	0.35	5.6 to 6	–	–	–	1923 to 3580 Coulombs charge passed showing low to moderate chloride iron permeability	–

5.8. *Effects of type and forms of fibers*

The use of fibers in concrete mainly improves the flexural strength of concrete. Recently several authors used different types of fibers in LWSCC to enhance its mechanical properties. Aslani and Kelin (2018) conducted a comparative study to investigate the effect of PP and steel fibers on the compressive strength of LWSCC. Similar to normal weight concrete, compressive strength was observed increasing up to certain doses of fibers, and afterward, it started declining. The authors observed that the addition of 0.1% PP and 0.75% steel fibers show optimum compressive strength gain. The authors observed that incorporating 0.1% PP and 0.75% steel fibers improved the compressive strength of LWSCC by nearly 38% and 63%, respectively. Similar results were observed by Liu et al. (2019); authors also reported that a combination of steel fibers and PP fiber in LWSCC might provide better strength gain. Li et al. (2021b) suggested that the use of micro steel fibers in LWSCC might be beneficial compared to long steel fibers. Several authors used sustainable fibers such as banana fibers, glass fibers, and waste plastic fibers in LWSCC. Similar to PP and steel fibers, up to certain doses, improvement in compressive strength was noticed. The use of fibers in concrete at low concentrations restricts the crack formations which helped to improve the compressive strength. While higher concentrations of fibers in concrete might entrap some air voids in concrete. Moreover, a high volume of fibers might push the LWA leading to disrupting the homogeneous distribution of fibers and aggregates. Perhaps due to these phenomena, the use of high volume of fibers in LWSCC resulted declining in compressive strength.

5.9. *Effects of nanomaterials*

The use of small doses of nanomaterials in concrete was observed to have a significant impact on compressive strength (Sharma et al., 2020). However, there were very limited studies evaluating the impacts of different types of nanomaterials on the properties of LWSCC. But it is expected to have almost similar behavior as occurred in conventional concrete. Madandoust et al. (2011) conducted experimental studies on EPS-based LWSCC using nano-silica and silica fume. It was observed that when a small amount of cement was replaced with nano-silica, concrete samples achieve slightly higher strength. Afzali Naniz and Mazloom (2018) reveal that the use of 3% colloidal nano-silica might improve the

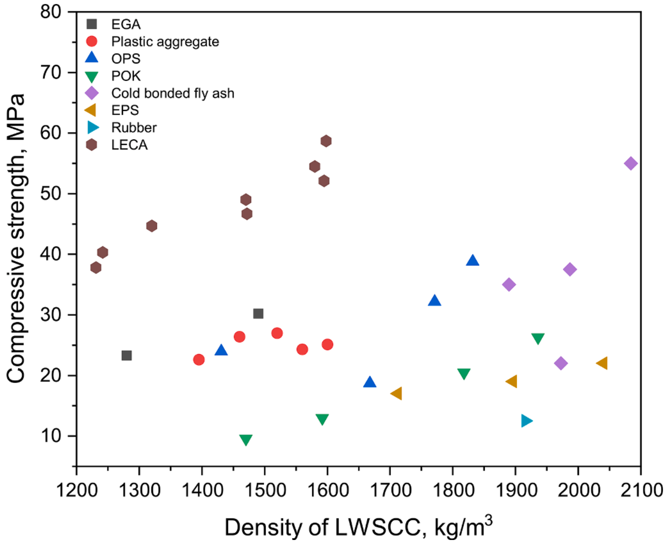

Figure 3. Relationship between density and compressive strength of LWSCC containing different types of LWA. (EGA (Yu et al., 2013); plastic aggregates (Yang et al., 2015); OPS (Ting et al., 2020); POK (Cheboub et al., 2020); cold bonded fly ash aggregates (Güneyisi et al., 2015b); EPS-(Ranjbar and Mousavi, 2015); Rubber-(Aslani and Kelin, 2018); LECA-(Corinaldesi and Moriconi, 2015)).

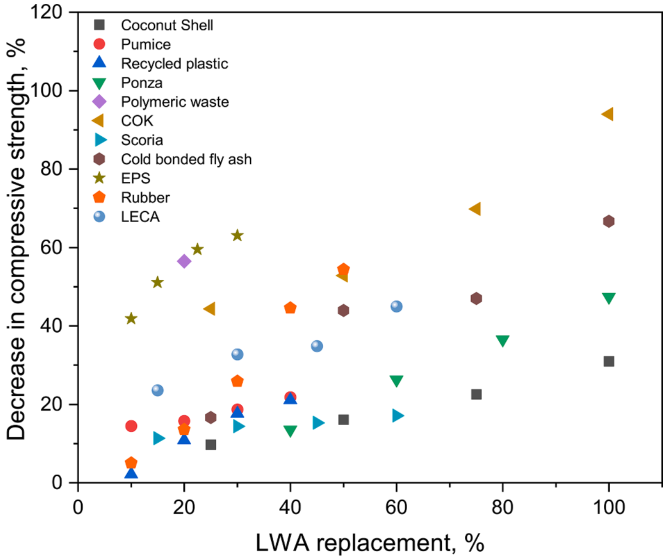

Figure 4. Relationship between LWA replacement concentration and decrease in compressive strength of LWSCC. (coconut shell (Muthusamy and Kolandasamy, 2015); pumice (Arun Kumar et al., 2020); recycled plastics (Faraj et al., 2021); ponza (Almawla et al., 2019); polymeric waste (da Silva et al., 2020); COK (Cheboub et al., 2020); scoria (Dolatabad et al., 2020); cold bonded fly ash (Güneyisi et al., 2015b); EPS (Madandoust et al., 2011); rubber (Lv et al., 2019a); LECA (Dolatabad et al., 2020)).

compressive strength of LWSCC by 21%. Similarly, Askari Dolatabad et al. (2020) reported the improvement in compressive strength of LWSCC by using nano-SiO_2, nano-TiO_2, and nano-Al_2O_3. Generally, the use of the above-mentioned nanomaterials in concrete accelerates the hydration of concrete and growth of hydration products leading to improvement in microstructure and compressive strength. However, exceeding the threshold quantity of these nanomaterials declines the strength that can be attributed to the agglomerations of nanomaterials (Afzali Naniz and Mazloom, 2018).

5.10. Effects of magnetic water

Water is a polar material whose molecules tend to cluster together via hydrogen bonding (Ebrahimi Jouzdani and Reisi, 2020). A magnetic field breaks hydrogen bonds, which lowers the aggregation of water molecules in a cluster (Su and Wu, 2003) and easily penetrates the cement particles leading to improved fresh and mechanical performances (Boguszynska et al., 2005; Su et al., 2000). Salehi and Mazloom (2019) reported that use of magnetic water in LWSCC production shows significant positive impacts on strength development. Authors reported an almost 17.6% enhancement in compressive strength by using magnetic water over tap water in the preparation of LWSCC. The enhancement can be attributed to magnetized water that easily penetrates the pores of cement paste and aids in the complete hydration of cement. In addition, the use of magnetized water provides dense and powerful ITZ leading to enhancement in compressive strength of LWSCC. A similar enhancement in the compressive strength of normal SCC using magnetic water was observed by several authors (Ebrahimi Jouzdani and Reisi, 2020; Ghorbani et al., 2020).

6. Durability properties of LWSCC

6.1. Water absorption

In terms of durability characteristics of concrete, water absorption properties might have notable impacts. Infiltration of water with harmful ions might severely damage the durability chrematistics of concrete. Basically, LWAC has a comparatively higher water absorption capacity than conventional concrete due to the presence of a higher volume of pores compared to conventional natural aggregates which may lead to higher water absorption properties. **Table 1** shows that depending on the type of LWA and its physical characteristics, the water absorption capacity might differ. Therefore, LWAC prepared with almost similar density to different LWAs' might show different water absorption capacity, however, the inclusion of a high amount of mineral admixture can have considerable impact on the water absorption capacity. **Table 4** suggested that LWSCC prepared with highly porous structured LWA such as perlite, cold bonded fly ash, and pumice may exhibit higher water absorption capacity. On the other hand, the use of EPS, rubber can weaken adhesion with cement-based materials leading to weaker ITZ and an increase in water absorption capacity (Angelin et al., 2020; Hilal et al., 2021; Medher et al., 2021; Ranjbar and Mousavi, 2015). Ghanbari et al. (2020) suggested that the use of small doses of nano-silica in LWSCC might significantly improve the water absorption capacity, incorporating 2% nano-silica showed almost 38% decrease in the water absorption capacity of LWSCC. Güneyisi et al. (2015a) reported that the combination of silica fume and fly ash can contribute in effectively lowering the water absorption capacity of LWSCC. The authors observed an almost 15% decrease in water absorption when a combination of fly ash and silica fume was used in the LWSCC. The incorporation of these pozzolans accelerates the formation of hydration products and fills the voids leading to improvement in water absorption properties. It was also observed that with the enhancement in hydration time, the effectiveness of these pozzolans becomes more effective due to improvement in microstructure and ITZ (Güneyisi et al., 2015c). Yashar and Behzad (2021) suggested that the use of SBR and PVR polymer coating on LWA might lower the water absorption of LWA and LWSCC. A similar observation was noticed by Adhikary (2022). The use of these polymers lower the formation of capillary pores and improves the ITZ leading to improvement in water absorption of LWSCC. So, from this literature study, it can be concluded that the use of LWA in LWSCC might enhance the risk of water absorption but with the inclusion of mineral admixtures and polymer coatings, these problems can be eliminated. Besides, the use of nanomaterials and hydrophobic coating, and curing conditions have positive impacts on the water absorption of concrete. Limited studies have been

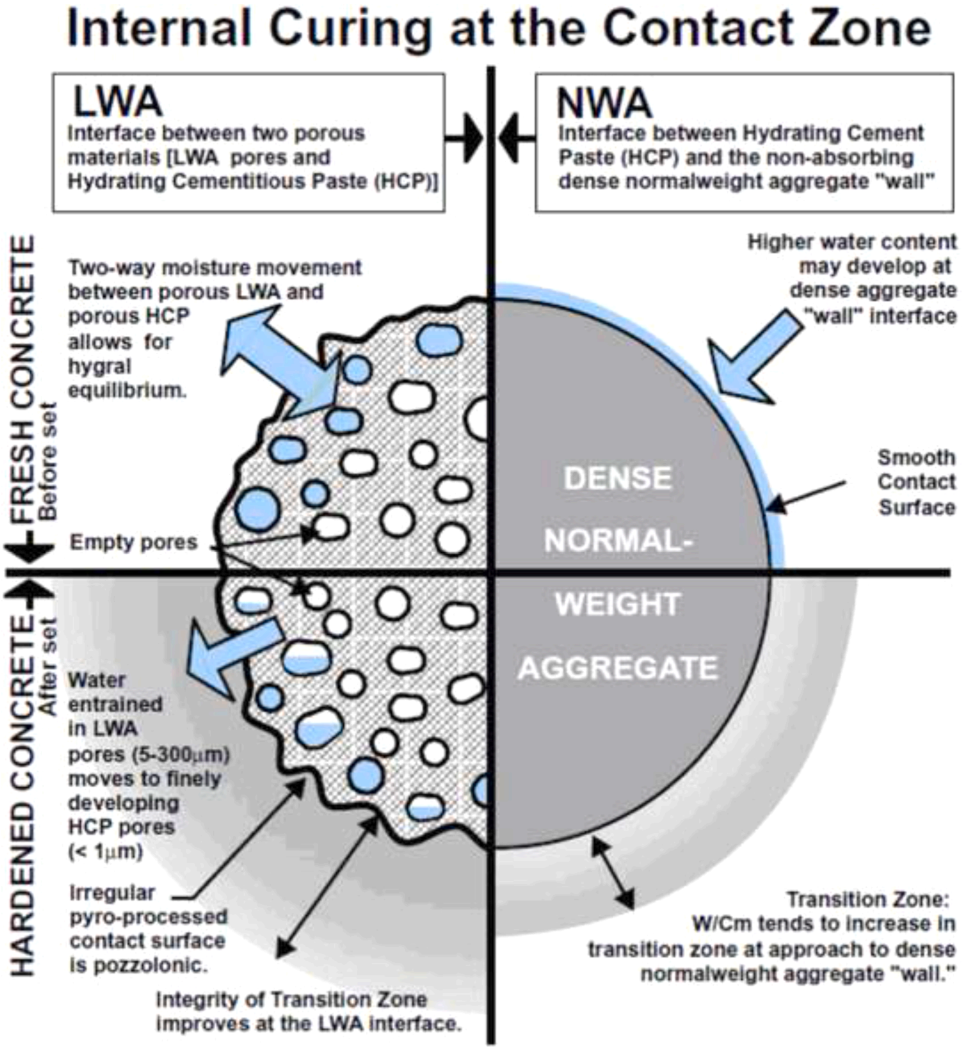

Figure 5. Internal curing of LWA (Adhikary et al., 2021; Namsone et al., 2017).

conducted evaluating the water absorption properties of LWSCC. Future studies might concentrate on investigating the impact of different parameters such as polymer coatings, nano materials, hydrophobic coatings, and curing conditions on the water absorption of LWSCC.

6.2. *Interfacial transitional zone*

Adhikary et al. (2021) reported the effects of the surface texture of LWA, moisture content, and density on the quality of ITZ that might have a profound impact on the durability and strength characteristics of concrete. The surface texture and adhesion properties of LWA might differ according to the type of LWA. It was observed that some LWA such as LECA, expanded glass, perlite, and scoria have good adhesion with cementitious material leading to better ITZ (Barnat-Hunek et al., 2018; Duplan et al., 2014; Yashar and Behzad, 2021; Yu et al., 2013). While EPS, rubber, COK, and polymeric waste have lower adhesion with cementitious materials leading to separation gaps in the transition zone (Angelin et al., 2020; Cheboub et al., 2020; da Silva et al., 2020; Ranjbar and Mousavi, 2015). The ITZ of LWSCC prepared with different types of LWA is presented in **Figure 6**. From the separation gaps, air and water can be penetrated with harmful ions, leading to a compromise in the durability characteristics of concrete. However, Liu et al. (2019) reported that the use of silica fume might slightly improve the ITZ and make denser concrete structures due to the formation of higher C-S-H gels. Yashar and Behzad (2021) reported that the use of PVR and SBR latex coating on LWA can create a dense structure in the ITZ. Adhikary (2022) used SBR and paraffin to coat the lightweight aggregates and reported similar improved denser ITZ. This can be attributed to the formation of monolithic interlayer bonding. So from this literature study, it is evident that the ITZ of LWSCC mainly depends upon the type of LWA, some LWA may have lower adhesion but the use of silica fume and polymer coatings can help to mitigate the weaker adhesion and ITZ.

6.3. *Drying shrinkage*

Literature studies indicate that the drying shrinkage of LWSCC largely depends on the water/binder ratio, type of aggregate and aggregate content (Güneyisi et al., 2015a; Nahhab and Ketab, 2020; Yashar and Behzad, 2021). A higher rate of drying shrinkage in concrete might result in cracks leading to compromise in durability. It was observed that the drying shrinkage of LWSCC increased from 90 to 120 days depending upon the type of LWA used in the concrete and thereafter it stabilized (Lv et al., 2019b; Nahhab and Ketab, 2020). Güneyisi et al. (2015a) suggested that LWA with higher water absorption capacity might enhance the risk of drying shrinkage. As indicated in **Table 1**, the water absorption capacity of LWA is largely dependent upon the type of LWA and its size. So, it is expected to have an inconsistence in the drying shrinkage of LWSCC prepared by the type of LWA with different gradings. Yashar and Behzad (2021) conducted a comparative analysis of drying shrinkage of LWSCC prepared with two different types of LWA

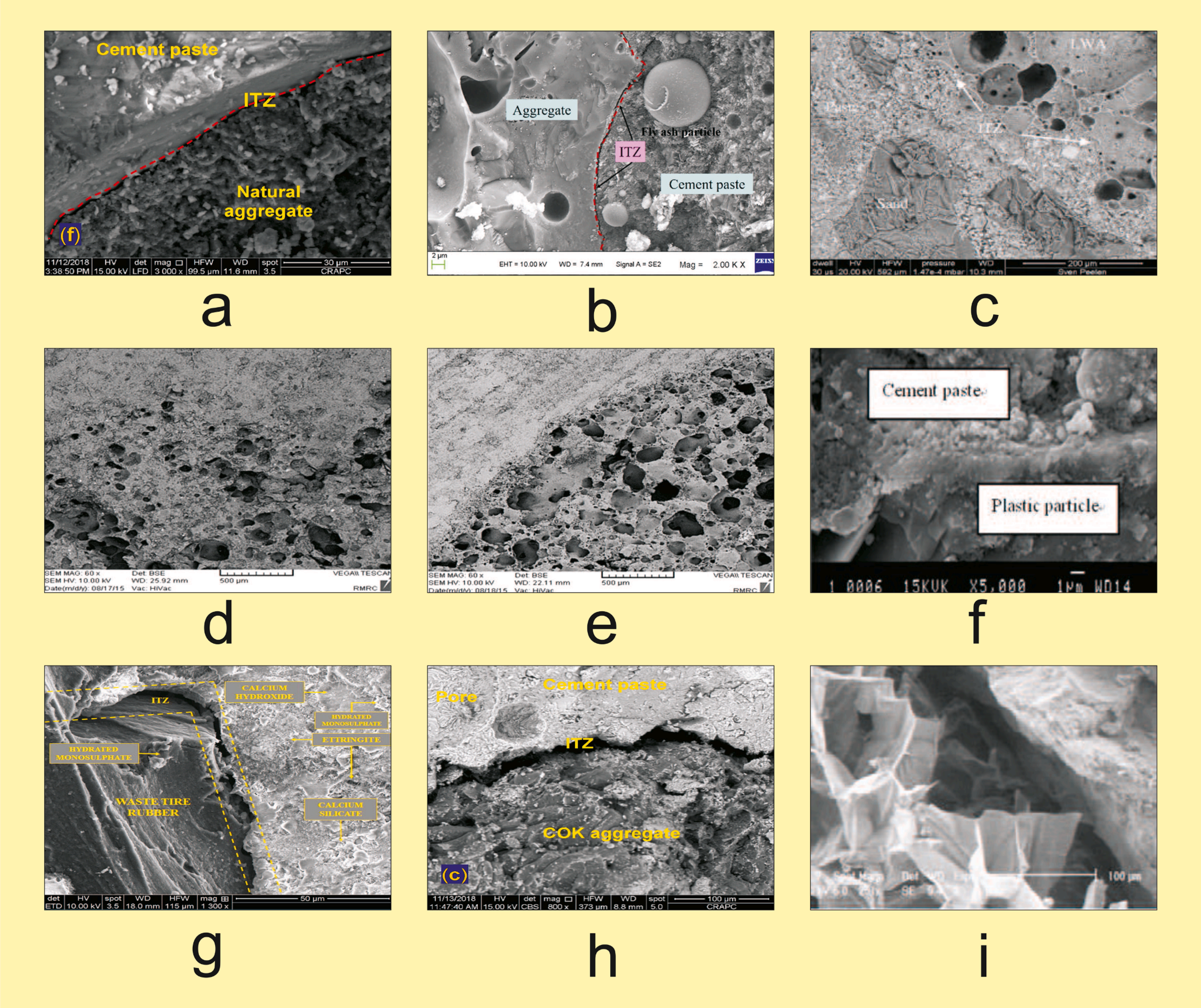

Figure 6. ITZ of LWSCC is prepared with different types of aggregates: a. natural aggregates (Cheboub et al., 2020); b. shale ceramsite (Li et al., 2021b); c. EGA (Yu et al., 2013); d. scoria (Yashar and Behzad, 2021); e. LECA (Yashar and Behzad, 2021); f. plastic (Yang et al., 2015); g. rubber (Angelin et al., 2020); h. COK (Cheboub et al., 2020); i. EPS (Ranjbar and Mousavi, 2015).

and reported that LWA with higher water absorption capacity exhibits a higher drying shrinkage rate. Authors reported almost 31% lower drying shrinkage of LECA-based LWSCC compared to scoria based LWSCC. Nahhab and Ketab (2020) observed a higher rate of drying shrinkage of LWSCC containing a high volume of LWA compared to LWSCC containing a low volume of LWA. This enhancement in drying shrinkage of LWSCC can be explained with lower stiffness and modulus of elasticity of LWA compared to conventional aggregates. Due to this fact, cement paste faces lower restrictions leading to a higher rate of drying shrinkage. Authors also reported that the use of the smaller grain of LECA exhibits a higher drying shrinkage value, it could be due to the higher water absorption capacity of small grain LECA compared to larger grain. Authors reported an almost 27% lower drying shrinkage value of 20 mm LECA added LWSCC compared to LWSCC prepared with 10 mm LECA. However, it was evident that the use of fibers, nano-silica, and a lower water/binder ratio improved the drying shrinkage of LWSCC (Corinaldesi and Moriconi, 2015; Güneyisi et al., 2015a; Nahhab and Ketab, 2020). At greater water/binder ratio, free water evaporates and enhances the risk of shrinkage while the addition of nano-silica and lower water binder ratio make concrete denser leading to improvement in drying shrinkage. Generally, fibers have a greater elastic modulus that help to mitigate the higher risk of drying shrinkage of concrete. Shi and Wu (2005) reported that the use of glass powder in LWSCC shows finer drying shrinkage compared to coal fly ash added to LWSCC. This can be explained by the tendency of fly ash to absorb some water, while the addition of glass powder can make concrete denser leading to lower drying shrinkage value. ACI committee suggested that the use of a partial amount of natural aggregate in LWAC might significantly improve the drying shrinkage of concrete. The addition of natural aggregate can make concrete stronger and lower the water absorption capacity leading to improvement in drying shrinkage. So, from this extensive literature study, it is clear that LWSCC might face higher drying shrinkage risk due to the higher water absorption capacity of LWA. But the use of a partial amount of natural aggregates, glass powder, ultrafine pozzolans, and fibers can mitigate this risk of higher drying shrinkage of LWSCC.

6.4. Electrical resistivity

The electrical resistivity of concrete evaluates the risk of corrosion of rebar, a higher risk of corrosion might compromise the durability of concrete. In another words, the electrical resistivity of concrete describes the potentiality to hold out the movement of charged ions. The electrical resistivity of concrete shares an inversely proportional relationship with corrosion risk, higher electrical resistivity represents a lower risk of corrosion occurrence. Ranjbar and Mousavi (2015) studied the impacts of EPS content on the electrical resistivity of LWSCC and reported that a higher volume of EPS exhibits a lower corrosion risk. The increase in EPS content in the concrete results in a decline in electrical resistivity. The resistivity of the control sample was reported at 19 kΩ-cm, which decreased to 10 kΩ-cm for the concrete sample containing 30% EPS. While the use of scoria, LECA, and EGA added to LWSCC shows a higher risk of corrosion (Mehrinejad Khotbehsara et al., 2017; Spiesz et al., 2013). However, it was observed that the use of nano-silica and zeolite powder lowers the water binder ratio and exhibits higher electrical resistivity, which represents an improvement in corrosion occurrence risks (Afzali Naniz and Mazloom, 2018; Ghanbari et al., 2020; Spiesz et al., 2013). This improvement might be due to the pozzolanic activity of these pozzolans that improve the microstructure. Tumidajski et al. (1996) reported that higher porosity in concrete might lower the electrical resistivity. So, it can be understood that the use of a high volume of porous structured LWA might result in lower electrical resistivity. Azarsa and Gupta (2017) suggested the type of aggregate, size of aggregate and curing conditions have notable impacts on the electrical resistivity of concrete. There were very limited studies evaluating the electrical resistivity of LWSCC, further detailed research is required to investigate the electrical resistivity of different LWA added LWSCC.

6.5. Freeze-thaw resistance

Freeze-thaw resistance of concrete is notably impacted by the porosity of concrete; higher porosity of concrete mitigate the micro-crack damages provided by recrystallization of ice. Spiesz et al. (2013) reported that LWSCC having higher porosity and pore connectivity provides greater frost resistance. The authors suggested that the use of EGA in LWSCC can provide excellent frost resistance. Shi and Wu (2005) reported that expanded shale added LWSCC also shows excellent frost resistance. The relative dynamic modulus of elasticity of LWSCC remains almost 60% even after 320 freezing cycles. Barnat-Hunek et al. (2018) suggested that perlite added to LWSCC might show satisfactory frost resistance at a lower concentration of perlite in LWSCC. The frost resistance of LWSCC can differ from LWAC due to the use of a higher volume of mineral admixtures in LWSCC. There are very limited studies presenting the evaluation of frost resistance of LWSCC, and further detailed studies are required to reach on worthy conclusion. However, on the basis of the literature study, it can be understood that LWSCC can provide better frost resistance than conventional SCC due to the high volume of porosity.

7. Discussion

The comprehensive literature study suggests that the workability performance of LWSCC mainly depends on the void content, packing density, type, and properties of LWA. Porous structured LWA can absorb water during the mixing process leading to a decrease in workability, in that case, pre-wetting and pre-treating with hydrophobic coatings can help to improve the workability of LWSCC. Like conventional SCC, the similar impact of superplasticizer doses, water/binder ratio, fibers, and supplementary cementitious materials such as fly ash, and silica fume were observed useful for LWSCC. **Table 3** shows the incorporation of fly ash, silica fume, limestone powder, and blast-furnace slag, these are the most used supplementary cementitious materials for LWSCC production. Due to very light density, lightweight aggregates have a tendency to float on the top of the concrete mix promoting segregation. However, proper aggregate gradation, packing density, and binding material concentration can help to provide self-compatibility even at nearly 850-1400 kg/m^3 density. It can be observed from **Table 3** that LWSCC at a lower density might increase the demand of binding material to satisfy the requirements of self-compacting concrete. Although, the development of a new LWSCC mix design obtained from the mixing and trial method with increased binding paste concentration might help to achieve target workability. There is no available guideline on LWSCC and perhaps the new mix design of LWSCC can help to develop a simple guideline for the preparation of LWSCC.

From the extensive literature studies, it is confirmed that the concrete mix design, type of LWA, and its characteristics are the prime influential factors affecting the strength development of LWSCC. Other factors like water/binder ratio, inclusion of pozzolan, fibers, and nanomaterials show almost similar behaviors as in conventional concrete. Generally, due to the weakened strength of LWA, LWSCC achieves lower compressive strength than the conventional LWSCC. **Figure 3** and **Figure 4** represent the relationship between the density and compressive strength suggesting LWA replacement concentration and its effect on the compressive strength of LWSCC containing different types of LWAs'. Porous structured LWA also provides internal curing that might also have positive impact on the hydration of cement (Adhikary et al., 2021). Interestingly, LWA aggregate absorbs water during the concrete mixing process and supplies the water through a curing process that help to complete the hydration processing. **Figure 5** shows the internal curing of LWA, there are limited studies mentioning the impact of curing conditions on the strength of LWSCC, further studies might concentrate on it. It was observed that most of the LWSCC having a density of more than 1200 kg/m^3 satisfy the ACI-213R-03 2003 and ACI-213R-2014 requirements to be used as structural concrete. Several authors developed LWSCC even below 1100 kg/m^3 density using very lightweight aggregates; due to the higher volume of pores, LWSCC fails to gain sufficient strength to be used as structural concrete. However, these kind of LWSCC can be very beneficial for thermal insulation purposes due to their greater thermal resistance properties. The comprehensive literature review demonstrates that the physical and chemical properties of LWA have notable impacts on the durability of LWAC. LWAC prepared with porous LWA such as perlite, pumice, expanded clay, cold-bonded fly ash, and expanded glass aggregate concrete exhibit a higher risk of water absorption capacity increasing the rate of drying shrinkage. The use of expanded clay, EGA, and scoria in higher volumes also increases the risk of corrosion in concrete. However, concrete incorporating EPS shows improved corrosion resistance. It was also observed that the incorporation of pozzolanic fillers at an optimum level might significantly lower the rate of water absorption, corrosion, and drying shrinkage of LWAC. Literature studies indicate that the combination of natural and LWA is beneficial in terms of strength, water absorption, corrosion resistance, and drying shrinkage. Despite the other durability characteristics, LWAC shows excellent frost resistance over conventional concrete.

8. Conclusion

This literature review provides a detailed study of the physical, mechanical, and mineral composition of different lightweight aggregates. It also provides detailed information about the impact of different types of lightweight aggregate on the fresh, mechanical, and durability properties of lightweight self-compacting concrete. From the comprehensive literature study following conclusions can be drawn.

- The physical and mechanical characteristics of lightweight aggregate are varied according to their type and size. The bulk density of different lightweight aggregate lies in the range of 10 to 1300 kg/m^3 having up to 20% water absorption capacity. The cell size of LWA can lead to variation in strength and bulk density of lightweight aggregate concrete, greater cell size of LWA lead to a decrease in density and strength performance of LWA.

- The use of lightweight aggregates in lightweight self-compacting concrete can increase the risk of water absorption but with the inclusion of mineral admixtures and polymer coatings, this problem can be eliminated.
- The surface texture and adhesion properties of lightweight aggregate might differ according to the type of LWA; some LWAs' may have lower adhesion, however, the use of silica fume and polymer coatings can help to mitigate the weaker adhesion and ITZ.
- The workability of lightweight self-compacting concrete is largely dependent upon the void content and packing density, type, and properties of lightweight aggregate. Porous structured lightweight aggregate absorb some water during the mixing process and lower the workability, use of pre-wetting and pre-treatment with polymers and water glass can positively contribute on workability. Like normal self-compacting concrete, almost similar impact of incorporation of pozzolanic addition, fiber, superplasticizer, and water/binder ratio was noticed in lightweight self-compacting concrete.
- The strength of lightweight self-compacting concrete generally depends on the concrete mix design, type of lightweight aggregate, and its characteristics. Other factors like water/binder ratio, inclusion of pozzolan, fiber, and nanomaterials have almost similar behaviors that can be observed in conventional concrete. However, the inclusion of nano-materials such as nano-SiO_2, nano-TiO_2; fibers, and magnetic water can contribute to enhance the strength properties.
- Lightweight self-compacting concrete having a density of more than 1200 kg/m^3 satisfying the ACI-213R-03 2003 and ACI-213R-2014 requirements to be used as structural concrete. Density below 1100 kg/m^3 fails to gain sufficient strength to use as structural concrete, however, these kinds of lightweight self-compacting concrete can be very beneficial for thermal insulation purposes due to their greater thermal resistance properties.
- Lightweight self-compacting concrete without pozzolanic addition might face a higher risk of corrosion while the addition of ultrafine mineral admixtures with a lower water binder ratio can successfully mitigate these problems. However, despite the lower strength, higher water absorption, and corrosion risk lightweight self-compacting concrete shows excellent frost resistance.
- Due to the high volume of porous structured lightweight aggregate, lower electrical resistivity is generally observed in lightweight self-compacting concrete; the type of aggregate, size of aggregate, and curing conditions significantly affect the electrical resistivity of concrete.

Future prospective

- In laboratory work, several mix designs of LWSCC have been developed, however, validation of this work requires their application on real construction sites. In this perspective, the mixing and trial method through manipulating mixing compositions might help to reach target workability and hardened properties. The demographic analysis of the LWSCC mix design and its performance is essential to develop the guidelines for the widespread application of the LWSCC mix design.
- Most of the research articles concentrated on the fresh and hardened properties of LWSCC, further detailed studies are required on the durability assessment of different LWAs' added LWSCC.
- LWSCC below 1200 kg/m3 has been developed a number of times using different types of LWAs', but only a few studies presented the thermal conductivity of those composites. However, development of thermal insulating LWSCC is only restricted to research

Declaration of interests

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.

References

Abdelaziz, G.E., 2010. A study on the performance of lightweight self-consolidated concrete. Mag. Concr. Res. 62, 39–49. https://doi.org/10.1680/macr.2008.62.1.39.

ACI-213R-14, 2014. Guide for Structural Lightweightaggregate Concrete. ACI Committee 213. American Concrete Institute, Farmington Hills, MI, pp. 48333–49094.

Adhikary, S.K., 2022. The influence of pre-coated EGA and aerogel on the properties of lightweight self-compacting cementitious composites. Mater. Today Commun.

Adhikary, S.K., Ashish, D.K., Rudžionis, Ž., 2021. Expanded glass as light-weight aggregate in concrete – A review. J. Clean. Prod. 313C, 127848 https://doi.org/10.1016/j.jclepro.2021.127848.

Adhikary, S.K., Rudžionis, Ž., Tučkutė, S., 2022. Characterization of novel lightweight self-compacting cement composites with incorporated expanded glass, aerogel, zeolite and fly ash. Case Stud. Constr. Mater. 16, e00879. https://doi.org/10.1016/j.cscm.2022.e00879.

Afzali Naniz, O., Mazloom, M., 2018. Effects of colloidal nano-silica on fresh and hardened properties of self-compacting lightweight concrete. J. Build. Eng. 20, 400–410. https://doi.org/10.1016/j.jobe.2018.08.014.

Agwa, I.S., Omar, O.M., Tayeh, B.A., Abdelsalam, B.A., 2020. Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. Constr. Build. Mater. 235, 117541 https://doi.org/10.1016/j.conbuildmat.2019.117541.

Almawla, S.A., Mohammed, M.K., Al-Hadithi, A.I., 2019. Fresh and mechanical properties of self-compacting lightweight concrete containing ponza aggregates. In: Proc. - Int. Conf. Dev. eSystems Eng. DeSE October-20, pp. 100–104. https://doi.org/10.1109/DeSE.2019.00028.

Altalabani, D., Bzeni, D.K.H., Linsel, S., 2020a. Mechanical properties and load deflection relationship of polypropylene fiber reinforced self-compacting lightweight concrete. Constr. Build. Mater. 252, 119084 https://doi.org/10.1016/j.conbuildmat.2020.119084.

Altalabani, D., Linsel, S., Bzeni, D.K.H., 2020b. Rheological Properties and Strength of Polypropylene Fiber-Reinforced Self-compacting Lightweight Concrete Produced with Ground Limestone. Arab. J. Sci. Eng. 45, 4171–4185. https://doi.org/10.1007/s13369-020-04410-z.

Andiš̈-Ṡakć, É., Ramyar, K., Yazćcá, Ź., Yozcurtcu, E., 2009. Self-compacting lightweight aggregate concrete: Design and experimental study. Mag. Concr. Res. 61, 519–527. https://doi.org/10.1680/macr.2008.00024.

Angelin, A.F., Cecche, R.C., Osório, W.R., Gachet, L.A., 2020. Evaluation of efficiency factor of a self-compacting lightweight concrete with rubber and expanded clay contents. Constr. Build. Mater. 257, 119573 https://doi.org/10.1016/j.conbuildmat.2020.119573.

Arun Kumar, B., Sangeetha, G., Srinivas, A., Awoyera, P.O., Gobinath, R., Venkata Ramana, V., 2020. Models for Predictions of Mechanical Properties of Low-Density Self-compacting Concrete Prepared from Mineral Admixtures and Pumice Stone. Adv. Intell. Syst. Comput. 1057, 677–690. https://doi.org/10.1007/978-981-15-0184-5_58.

Askari Dolatabad, Y., Kamgar, R., Gouhari Nezad, I., 2020. Rheological and Mechanical Properties, Acid Resistance and Water Penetrability of Lightweight Self-Compacting Concrete Containing Nano-SiO2, Nano-TiO2 and Nano-Al2O3. Iran. J. Sci. Technol. - Trans. Civ. Eng. 44, 603–618. https://doi.org/10.1007/s40996-019-00328-1.

Aslani, F., Kelin, J., 2018. Assessment and development of high-performance fi bre-reinforced lightweight self-compacting concrete including recycled crumb rubber aggregates exposed to elevated temperatures. J. Clean. Prod. 200, 1009–1025. https://doi.org/10.1016/j.jclepro.2018.07.323.

Aslani, F., Ma, G., 2018. Normal and High-Strength Lightweight Self-Compacting Concrete Incorporating Perlite, Scoria, and Polystyrene Aggregates at Elevated Temperatures. J. Mater. Civ. Eng. 30, 04018328 https://doi.org/10.1061/(asce)mt.1943-5533.0002538.

Assaad, J.J., El Mir, A., 2020. Durability of polymer-modified lightweight flowable concrete made using expanded polystyrene. Constr. Build. Mater. 249, 118764 https://doi.org/10.1016/j.conbuildmat.2020.118764.

ASTM C330 - 05, 2005. Standard Specification for Lightweight Aggregates for Structural Concrete. ASTM International, West Conshohocken, PA.

Awoyera, P.O., Akinwumi, I.I., Karthika, V., Gobinath, R., Gunasekaran, R., Lokesh, N., Manikandan, M., Narmatha, T., 2020. Lightweight Self-Compacting Concrete Incorporating Industrial Rejects and Mineral Admixtures : Strength and Durability Assessment 1779–1785.

Azarsa, P., Gupta, R., 2017. Resistivity of Concrete for ElectricalDurability Evaluation: A Review. Adv. Mater. Sci. Eng. 2017, 1–30.

Barnat-Hunek, D., Góra, J., Andrzejuk, W., Lagód, G., 2018. The microstructure-mechanical properties of hybrid fibres-reinforced self-compacting lightweight concrete with perlite aggregate. Materials (Basel) 11. https://doi.org/10.3390/ma11071093.

Boguszynska, J., Brown, M.C.A., Mcdonald, P.J., Mitchell, J., Mulheron, M., Tritt-goc, J., Verganelakis, D.A., 2005. Magnetic resonance studies of cement based materials in inhomogeneous magnetic fields. Cem. Concr. Res. 35, 2033–2040. https://doi.org/10.1016/j.cemconres.2005.06.012.

Cheboub, T., Senhadji, Y., Khelafi, H., Escadeillas, G., 2020. Investigation of the engineering properties of environmentally-friendly self-compacting lightweight mortar containing olive kernel shells as aggregate. J. Clean. Prod. 249 https://doi.org/10.1016/j.jclepro.2019.119406.

Corinaldesi, V., Moriconi, G., 2015. Use of synthetic fibers in self-compacting lightweight aggregate concretes. J. Build. Eng. 4, 247–254. https://doi.org/10.1016/j.jobe.2015.10.006.

Cozzarini, L., Marsich, L., Ferluga, A., Schmid, C., 2020. Life cycle analysis of a novel thermal insulator obtained from recycled glass waste. Dev. Built Environ. 3, 100014 https://doi.org/10.1016/j.dibe.2020.100014.

Cui, H.Z., Lo, T.Y., Memon, S.A., Xu, W., 2012. Effect of lightweight aggregates on the mechanical properties and brittleness of lightweight aggregate concrete. Constr. Build. Mater. 35, 149–158. https://doi.org/10.1016/j.conbuildmat.2012.02.053.

da Silva, L.R.R., da Silva, J.A., Francisco, M.B., Ribeiro, V.A., de Souza, M.H.B., Capellato, P., Souza, M.A., Dos Santos, V.C., Gonçalves, P.C., Melo, M.de L.N.M., 2020. Polymeric waste from recycling refrigerators as an aggregate for self-compacting concrete. Sustain 12, 1–19. https://doi.org/10.3390/su12208731.

Dolatabad, Y.A., Kamgar, R., Jamali Tazangi, M.A., 2020. Effects of perlite, leca, and scoria as lightweight aggregates on properties of fresh and hard self-Compacting concretes. J. Adv. Concr. Technol. 18, 633–647. https://doi.org/10.3151/JACT.18.633.

Domagała, L., 2015. The effect of lightweight aggregate water absorption on the reduction of water-cement ratio in fresh concrete. Procedia Eng 108, 206–213. https://doi.org/10.1016/j.proeng.2015.06.139.

Duplan, F., Abou-Chakra, A., Turatsinze, A., Escadeillas, G., Brule, S., Masse, F., 2014. Prediction of modulus of elasticity based on micromechanics theory and application to low-strength mortars. Constr. Build. Mater. 50, 437–447. https://doi.org/10.1016/j.conbuildmat.2013.09.051.

Ebrahimi Jouzdani, B., Reisi, M., 2020. Effect of magnetized water characteristics on fresh and hardened properties of self-compacting concrete. Constr. Build. Mater. 242, 118196 https://doi.org/10.1016/j.conbuildmat.2020.118196.

Erdem, S., 2014. X-ray computed tomography and fractal analysis for the evaluation of segregation resistance, strength response and accelerated corrosion behaviour of self-compacting lightweight concrete. Constr. Build. Mater. 61, 10–17. https://doi.org/10.1016/j.conbuildmat.2014.02.070.

Faraj, R.H., Far, A., Sherwani, H., Hama, L., Ibrahim, D.F., 2021. Rheological behavior and fresh properties of self-compacting high strength concrete containing recycled PP particles with fly ash and silica fume blended. J. Build. Eng. 34, 101667 https://doi.org/10.1016/j.jobe.2020.101667.

Feen, O.S., Mohamed, R.N., Mohamed, A., Khalid, N.H.A., 2017. Effects of coarse palm oil clinker on properties of self-compacting lightweight concrete. J. Teknol. 79, 111–120. https://doi.org/10.11113/jt.v79.10593.

Floyd, R.W., Hale, W.M., Bymaster, J.C., 2015. Effect of aggregate and cementitious material on properties of lightweight self-consolidating concrete for prestressed members. Constr. Build. Mater. 85, 91–99. https://doi.org/10.1016/j.conbuildmat.2015.03.084.

Gesoğlu, M., Güneyisi, E., Özturan, T., Öz, H.Ö., Asaad, D.S., 2014. Self-consolidating characteristics of concrete composites including rounded fine and coarse fly ash lightweight aggregates. Compos. Part B Eng. 60, 757–763. https://doi.org/10.1016/j.compositesb.2014.01.008.

Ghanbari, M., Kohnehpooshi, O., Tohidi, M., 2020. Experimental study of the combined use of fiber and nano silica particles on the properties of lightweight self compacting concrete. Int. J. Eng. Trans. B Appl. 33, 1499–1511. https://doi.org/10.5829/ije.2020.33.08b.08.

Ghorbani, S., Sharifi, S., Rokhsarpour, H., Shoja, S., Gholizadeh, M., Rahmatabad, M.A.D., de Brito, J., 2020. Effect of magnetized mixing water on the fresh and hardened state properties of steel fibre reinforced self-compacting concrete. Constr. Build. Mater. 248, 118660 https://doi.org/10.1016/j.conbuildmat.2020.118660.

Gonen, T., 2018. Mechanical and fresh properties of ber reinforced self-compacting lightweight concrete.

Gonen, T., Yazicioglu, S., 2018. The Effect of Curing Conditions on Permeation of Self-Compacting Lightweight Concrete with Basaltic Pumice Aggregate. Arab. J. Sci. Eng. 43, 5157–5164. https://doi.org/10.1007/s13369-017-2990-4.

Gong, X.Z., Tian, Y.L., Zhang, L.J., 2018. A Comparative Life Cycle Assessment of Typical Foam Glass Production. Mater. Sci. Forum 913, 1054–1061. https://doi.org/10.4028/www.scientific.net/MSF.913.1054.

Grabois, T.M., Cordeiro, G.C., Toledo Filho, R.D., 2016. Fresh and hardened-state properties of self-compacting lightweight concrete reinforced with steel fibers. Constr. Build. Mater. 104, 284–292. https://doi.org/10.1016/j.conbuildmat.2015.12.060.

Güneyisi, E., Gesoglu, M., Azez, O.A., Öz, H.Ö., 2016. Effect of nano silica on the workability of self-compacting concretes having untreated and surface treated lightweight aggregates. Constr. Build. Mater. 115, 371–380. https://doi.org/10.1016/j.conbuildmat.2016.04.055.

Güneyisi, E., Gesoglu, M., Azez, O.A., Öz, H.Ö., 2015a. Physico-mechanical properties of self-compacting concrete containing treated cold-bonded fly ash lightweight aggregates and SiO2 nano-particles. Constr. Build. Mater. 101, 1142–1153. https://doi.org/10.1016/j.conbuildmat.2015.10.117.

Güneyisi, E., Gesoğlu, M., Booya, E., 2012. Fresh properties of self-compacting cold bonded fly ash lightweight aggregate concrete with different mineral admixtures. Mater. Struct. Constr. 45, 1849–1859. https://doi.org/10.1617/s11527-012-9874-6.

Güneyisi, E., Gesołlu, M., Altan, I., Öz, H.Ö., 2015b. Utilization of cold bonded fly ash lightweight fine aggregates as a partial substitution of natural fine aggregate in self-compacting mortars. Constr. Build. Mater. 74, 9–16. https://doi.org/10.1016/j.conbuildmat.2014.10.021.

Güneyisi, E., Gesołlu, M., Booya, E., Mermerdaş, K., 2015c. Strength and permeability properties of self-compacting concrete with cold bonded fly ash lightweight aggregate. Constr. Build. Mater. 74, 17–24. https://doi.org/10.1016/j.conbuildmat.2014.10.032.

Heiza, K., Eid, F., Masoud, T., 2018. Lightweight self-compacting concrete with light expanded clay aggregate (LECA). MATEC Web Conf 162, 1–7. https://doi.org/10.1051/matecconf/201816202031.

Hemalatha, T., Ramaswamy, A., 2017. A review on fly ash characteristics – Towards promoting high volume utilization in developing sustainable concrete. J. Clean. Prod. 147, 546–559. https://doi.org/10.1016/j.jclepro.2017.01.114.

Hilal, N., Hamah Sor, N., Faraj, R.H., 2021. Development of eco-efficient lightweight self-compacting concrete with high volume of recycled EPS waste materials. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-021-14213-w.

Hossain, K.M.A., Hossain, M.A., Manzur, T., 2020. Structural performance of fiber reinforced lightweight self-compacting concrete beams subjected to accelerated corrosion. J. Build. Eng. 30, 101291 https://doi.org/10.1016/j.jobe.2020.101291.

Iqbal, S., Ali, A., Holschemacher, K., Bier, T.A., 2015. Mechanical properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC). Constr. Build. Mater. 98, 325–333. https://doi.org/10.1016/j.conbuildmat.2015.08.112.

Iqbal, S., Ali, A., Holschemacher, K., Ribakov, Y., Bier, T.A., 2017. Effect of fly ash on properties of self-compacting high strength lightweight concrete. Period. Polytech. Civ. Eng. 61, 81–87. https://doi.org/10.3311/PPci.8171.

Ismail, A.H., Kusbiantoro, A., Chin, S.C., Muthusamy, K., Islam, M., Tee, K.F., 2020. Pozzolanic reactivity and strength activity index of mortar containing palm oil clinker pretreated with hydrochloric acid. J. Clean. Prod. 242, 118565 https://doi.org/10.1016/j.jclepro.2019.118565.

Juradin, S., Baloevi, G., Harapin, A., 2012. Experimental testing of the effects of fine particles on the properties of the self-compacting lightweight concrete. Adv. Mater. Sci. Eng. 2012 https://doi.org/10.1155/2012/398567.

Kaffetzakis, M.I., Papanicolaou, C.G., 2016. Bond behavior of reinforcement in Lightweight Aggregate Self-Compacting Concrete. Constr. Build. Mater. 113, 641–652. https://doi.org/10.1016/j.conbuildmat.2016.03.081.

Kanadasan, J., Abdul Razak, H., 2015. Engineering and sustainability performance of self-compacting palm oil mill incinerated waste concrete. J. Clean. Prod. 89, 78–86. https://doi.org/10.1016/j.jclepro.2014.11.002.

Kanadasan, J., Razak, H.A., 2014. Mix design for self-compacting palm oil clinker concrete based on particle packing. Mater. Des. 56, 9–19. https://doi.org/10.1016/j.matdes.2013.10.086.

Karamloo, M., Mazloom, M., Payganeh, G., 2016a. Effects of maximum aggregate size on fracture behaviors of self-compacting lightweight concrete. Constr. Build. Mater. 123, 508–515. https://doi.org/10.1016/j.conbuildmat.2016.07.061.

Karamloo, M., Mazloom, M., Payganeh, G., 2016b. Influences of water to cement ratio on brittleness and fracture parameters of self-compacting lightweight concrete. Eng. Fract. Mech. 168, 227–241. https://doi.org/10.1016/j.engfracmech.2016.09.011.

Karthika, V., Awoyera, P.O., Akinwumi, I.I., Gobinath, R., Gunasekaran, R., Lokesh, N., 2018. STRUCTURAL PROPERTIES OF LIGHTWEIGHT SELF-COMPACTING CONCRETE MADE WITH PUMICE STONE AND MINERAL ADMIXTURES 48, 208–213.

Khankhaje, E., Salim, M.R., Mirza, J., Hussin, M.W., Rafieizonooz, M., 2016. Properties of sustainable lightweight pervious concrete containing oil palm kernel shell as coarse aggregate. Constr. Build. Mater. 126, 1054–1065. https://doi.org/10.1016/j.conbuildmat.2016.09.010.

Kurt, M., Aydin, A.C., Gül, M.S., Gül, R., Kotan, T., 2015. The effect of fly ash to self-compactability of pumice aggregate lightweight concrete. Sadhana - Acad. Proc. Eng. Sci. 40, 1343–1359. https://doi.org/10.1007/s12046-015-0337-y.

Kurt, M., Kotan, T., GüL, M.S., GüL, R., Aydin, A.C., 2016a. The effect of blast furnace slag on the self-compactability of pumice aggregate lightweight concrete. Sadhana - Acad. Proc. Eng. Sci. 41, 253–264. https://doi.org/10.1007/s12046-016-0462-2.

Kurt, M., Said, M., Gül, R., Cüneyt, A., Kotan, T., 2016b. The effect of pumice powder on the self-compactability of pumice aggregate lightweight concrete. Constr. Build. Mater. 103, 36–46. https://doi.org/10.1016/j.conbuildmat.2015.11.043.

Kwan, A.K.H., Mora, C.F., 2001. Effects of various shape parameters on packing of aggregate particles. Mag. Concr. Res. 53, 91–100. https://doi.org/10.1680/macr.2001.53.2.91.

Kwasny, J., Sonebi, M., Taylor, S.E., Bai, Y., Owens, K., Doherty, W., 2012. Influence of the Type of Coarse Lightweight Aggregate on Properties of Semilightweight Self-Consolidating Concrete. J. Mater. Civ. Eng. 24, 1474–1483. https://doi.org/10.1061/(asce)mt.1943-5533.0000527.

Li, J., Chen, J., Wan, C., Niu, J., 2021a. Flexural toughness and evaluation method of steel fiber reinforced self-compacting lightweight aggregate concrete. Constr. Build. Mater. 277, 122297 https://doi.org/10.1016/j.conbuildmat.2021.122297.

Li, J., Chen, Y., Wan, C., 2017. A mix-design method for lightweight aggregate self-compacting concrete based on packing and mortar film thickness theories. Constr. Build. Mater. 157, 621–634. https://doi.org/10.1016/j.conbuildmat.2017.09.141.

Li, J., Zhao, E., Niu, J., Wan, C., 2021b. Study on mixture design method and mechanical properties of steel fiber reinforced self-compacting lightweight aggregate concrete. Constr. Build. Mater. 267, 121019 https://doi.org/10.1016/j.conbuildmat.2020.121019.

Li, N., Zhang, S., Long, G., Jin, Z., Yu, Y., Zhang, X., Xiong, C., Li, H., 2021. Dynamic characteristics of lightweight aggregate self-compacting concrete by impact resonance method. Adv. Civ. Eng. 2021 https://doi.org/10.1155/2021/8811303.

Liu, J., Li, Z., Zhang, W., Jin, H., Xing, F., Tang, L., 2022. The impact of cold-bonded artificial lightweight aggregates produced by municipal solid waste incineration bottom ash (MSWIBA) replace natural aggregates on the mechanical, microscopic and environmental properties, durability of sustainable concrete. J. Clean. Prod. 337, 130479 https://doi.org/10.1016/j.jclepro.2022.130479.

Liu, X., Chia, K.S., Zhang, M.H., 2011. Water absorption, permeability, and resistance to chloride-ion penetration of lightweight aggregate concrete. Constr. Build. Mater. 25, 335–343. https://doi.org/10.1016/j.conbuildmat.2010.06.020.

Liu, X., Wu, T., Yang, X., Wei, H., 2019. Properties of self-compacting lightweight concrete reinforced with steel and polypropylene fibers. Constr. Build. Mater. 226, 388–398. https://doi.org/10.1016/j.conbuildmat.2019.07.306.

Lotfy, A., Hossain, K.M.A., Lachemi, M., 2016. Mix design and properties of lightweight self-consolidating concretes developed with furnace slag, expanded clay and expanded shale aggregates. J. Sustain. Cem. Mater. 5, 297–323. https://doi.org/10.1080/21650373.2015.1091999.

Lotfy, A., Hossain, K.M.A., Lachemi, M., 2015. Lightweight Self-consolidating Concrete with Expanded Shale Aggregates: Modelling and Optimization. Int. J. Concr. Struct. Mater. 9, 185–206. https://doi.org/10.1007/s40069-015-0096-5.

Lv, J., Du, Q., Zhou, T., He, Z., Li, K., 2019a. Fresh and Mechanical Properties of Self-Compacting Rubber Lightweight Aggregate Concrete and Corresponding Mortar 2019.

Lv, J., Zhou, T., Du, Q., Li, K., 2020. Experimental and analytical study on uniaxial compressive fatigue behavior of self-compacting rubber lightweight aggregate concrete. Constr. Build. Mater. 237, 117623 https://doi.org/10.1016/j.conbuildmat.2019.117623.

Lv, J., Zhou, T., Li, K., Sun, K., 2019b. Shrinkage Properties of Self-Compacting Rubber Lightweight Aggregate Concrete: Experimental and Analytical Studies. Materials (Basel) 12, 4059. https://doi.org/10.3390/ma12244059.

Lv, J., Zhou, T., Wu, H., Sang, L., He, Z., Li, G., Li, K., 2020. A New Composite Slab Using Crushed Waste Tires as Fine Aggregate in Self-Compacting Lightweight Aggregate Concrete. Materials 13, 2551. https://doi.org/10.3390/ma13112551.

Madandoust, R., Ranjbar, M.M., Yasin Mousavi, S., 2011. An investigation on the fresh properties of self-compacted lightweight concrete containing expanded polystyrene. Constr. Build. Mater. 25, 3721–3731. https://doi.org/10.1016/j.conbuildmat.2011.04.018.

Maekawa, K., K, O., 1999. Development of SCC's prototype." written in Japanese), Self-Compacting High-Performance Concrete. Soc. Syst. Inst. 20–32.

Mashiri, M.S., Vinod, J.S., Sheikh, M.N., Tsang, H.H., 2015. Shear strength and dilatancy behaviour of sand-tyre chip mixtures. Soils Found 55, 517–528. https://doi.org/10.1016/j.sandf.2015.04.004.

Mazaheripour, H., Ghanbarpour, S., Mirmoradi, S.H., Hosseinpour, I., 2011. The effect of polypropylene fibers on the properties of fresh and hardened lightweight self-compacting concrete. Constr. Build. Mater. 25, 351–358. https://doi.org/10.1016/j.conbuildmat.2010.06.018.

Medher, A.H., Al-Hadithi, A.I., Hilal, N., 2021. The Possibility of Producing Self-Compacting Lightweight Concrete by Using Expanded Polystyrene Beads as Coarse Aggregate. Arab. J. Sci. Eng. 46, 4253–4270. https://doi.org/10.1007/s13369-020-04886-9.

Medine, M., Trouzine, H., De Aguiar, J.B., Djadouni, H., 2020. Life Cycle Assessment of Concrete Incorporating Scrap Tire Rubber: Comparative Study. Nat. Technol. /Nat. Technol. 1–11.

Mehrinejad Khotbehsara, M., Mohseni, E., Ozbakkaloglu, T., Ranjbar, M.M., 2017. Retracted: Durability Characteristics of Self-Compacting Concrete Incorporating Pumice and Metakaolin. J. Mater. Civ. Eng. 29, 04017218 https://doi.org/10.1061/(asce)mt.1943-5533.0002068.

Mehta, A., Ashish, D.K., 2019. Silica fume and waste glass in cement concrete production: A review. J. Build. Eng. 100888 https://doi.org/10.1016/j.jobe.2019.100888.

Mehta, P.K., Monteiro, P.J.M., 2014. Concrete: microstructure, properties, and materials. McGraw-Hill Educ.

Miled, K., Sab, K., Le Roy, R., 2007. Particle size effect on EPS lightweight concrete compressive strength: Experimental investigation and modelling. Mech. Mater. 39, 222–240. https://doi.org/10.1016/j.mechmat.2006.05.008.

Milutienė, E., Staniškis, J.K., Kručius, A., Augulienė, V., Ardickas, D., 2012. Increase in buildings sustainability by using renewable materials and energy. Clean Technol. Environ. Policy 14, 1075–1084. https://doi.org/10.1007/s10098-012-0505-2.

Mo, K.H., Alengaram, U.J., Jumaat, M.Z., 2015a. Utilization of ground granulated blast furnace slag as partial cement replacement in lightweight oil palm shell concrete. Mater. Struct. Constr. 48, 2545–2556. https://doi.org/10.1617/s11527-014-0336-1.

Mo, K.H., Johnson Alengaram, U., Jumaat, M.Z., Yap, S.P., 2015b. Feasibility study of high volume slag as cement replacement for sustainable structural lightweight oil palm shell concrete. J. Clean. Prod. 91, 297–304. https://doi.org/10.1016/j.jclepro.2014.12.021.

Mo, K.H., Ling, T.C., Tan, T.H., Leong, G.W., Yuen, C.W., Shah, S.N., 2021. Alkali-silica reactivity of lightweight aggregate: A brief overview. Constr. Build. Mater. 270, 121444 https://doi.org/10.1016/j.conbuildmat.2020.121444.

Mohajerani, A., Burnett, L., Smith, J.V., Markovski, S., Rodwell, G., Rahman, M.T., Kurmus, H., Mirzababaei, M., Arulrajah, A., Horpibulsuk, S., Maghool, F., 2020. Recycling waste rubber tyres in construction materials and associated environmental considerations: A review. Resour. Conserv. Recycl. 155, 104679 https://doi.org/10.1016/j.resconrec.2020.104679.

Mousa, A., Mahgoub, M., Hussein, M., 2018. Lightweight concrete in America: presence and challenges. Sustain. Prod. Consum. 15, 131–144. https://doi.org/10.1016/j.spc.2018.06.007.

Muthusamy, S., Kolandasamy, P., 2015. Samozbijajući lagani beton na visokim temperaturama. Gradjevinar 67, 329–338. https://doi.org/10.14256/JCE.1141.2014.

Naderi, V., Fouroghi-asl, A., Nourani, V., Ma, H., 2018. On the pore structures of lightweight self-compacting concrete containing silica fume. Constr. Build. Mater. 193, 557–564. https://doi.org/10.1016/j.conbuildmat.2018.09.080.

Nadesan, M.S., Dinakar, P., 2017. Structural concrete using sintered flyash lightweight aggregate: A review. Constr. Build. Mater. 154, 928–944. https://doi.org/10.1016/j.conbuildmat.2017.08.005.

Nahhab, A.H., Ketab, A.K., 2020. Influence of content and maximum size of light expanded clay aggregate on the fresh, strength, and durability properties of self-compacting lightweight concrete reinforced with micro steel fibers. Constr. Build. Mater. 233, 117922 https://doi.org/10.1016/j.conbuildmat.2019.117922.

Namsone, Elvija, Šahmenko, G., Korjakins, A., Namsone, Eva, 2017. Influence of Porous Aggregate on the Properties of Foamed Concrete. Constr. Sci. 19, 13–20. https://doi.org/10.1515/cons-2016-0006.

Napolano, L., Menna, C., Graziano, S.F., Asprone, D., D'Amore, M., De Gennaro, R., Dondi, M., 2016. Environmental life cycle assessment of lightweight concrete to support recycled materials selection for sustainable design. Constr. Build. Mater. 119, 370–384. https://doi.org/10.1016/j.conbuildmat.2016.05.042.

Nepomuceno, M.C.S., Pereira-de-Oliveira, L.A., Pereira, S.F., 2018. Mix design of structural lightweight self-compacting concrete incorporating coarse lightweight expanded clay aggregates. Constr. Build. Mater. 166, 373–385. https://doi.org/10.1016/j.conbuildmat.2018.01.161.

Nguyen, H.D., Truong, K.X.T., Nguyen, N.M., Do, T.T., 2018. Self-compacting lightweight aggregate concrete in Vietnam. IOP Conf. Ser. Mater. Sci. Eng. 365 https://doi.org/10.1088/1757-899X/365/3/032030.

Omar, A.T., Ismail, M.K., Hassan, A.A.A., 2020. Use of Polymeric Fibers in the Development of Semilightweight Self-Consolidating Concrete Containing Expanded Slate. J. Mater. Civ. Eng. 32, 04020067 https://doi.org/10.1061/(asce)mt.1943-5533.0003104.

Ozawa, K., Maekawa, K., Okamura, H., 1992. Development of high performance concrete. J. Fac. Eng. Univ. Tokyo, Ser. B.

Ozguven, A., Gunduz, L., 2012. Examination of effective parameters for the production of expanded clay aggregate. Cem. Concr. Compos. 34, 781–787. https://doi.org/10.1016/j.cemconcomp.2012.02.007.

Peter, A.E., Shiva Nagendra, S.M., Nambi, I.M., 2019. Environmental burden by an open dumpsite in urban India. Waste Manag 85, 151–163. https://doi.org/10.1016/j.wasman.2018.12.022.

Pierrehumbert, R., 2019. There is no Plan B for dealing with the climate crisis. Bull. At. Sci. 75, 215–221. https://doi.org/10.1080/00963402.2019.1654255.

Poongodi, K., Murthi, P., 2021. Correlation between compressive strength and elastic modulus of light weight self-compacting concrete using coconut shell as coarse aggregate. Aust. J. Struct. Eng. 22, 85–95. https://doi.org/10.1080/13287982.2021.1926061.

Poongodi, K., Murthi, P., 2020. Impact strength enhancement of banana fibre reinforced lightweight self-compacting concrete. Mater. Today Proc. 27, 1203–1209. https://doi.org/10.1016/j.matpr.2020.02.108.

Poongodi, K., Murthi, P., Gobinath, R., 2020. Evaluation of ductility index enhancement level of banana fibre reinforced lightweight self-compacting concrete beam. Mater. Today Proc. 39, 131–136. https://doi.org/10.1016/j.matpr.2020.06.397.

Rampradheep, G.S., Sivaraja, M., 2016. Experimental investigation on self-compacting self-curing concrete incorporated with the light weight aggregates. Brazilian Arch. Biol. Technol. 59, 1–11. https://doi.org/10.1590/1678-4324-2016161075.

Ranjbar, M.M., Mousavi, S.Y., 2015. Strength and durability assessment of self-compacted lightweight concrete containing expanded polystyrene. Mater. Struct. Constr. 48, 1001–1011. https://doi.org/10.1617/s11527-013-0210-6.

Ranjbar, N., Behnia, A., Alsubari, B., Moradi Birgani, P., Jumaat, M.Z., 2016. Durability and mechanical properties of self-compacting concrete incorporating palm oil fuel ash. J. Clean. Prod. 112, 723–730. https://doi.org/10.1016/j.jclepro.2015.07.033.

Rashad, A.M., 2018. Lightweight expanded clay aggregate as a building material – An overview. Constr. Build. Mater. 170, 757–775. https://doi.org/10.1016/j.conbuildmat.2018.03.009.

Rudžionis, Ž., Adhikary, S.K., Manhanga, F.C., Ashish, D.K., Ivanauskas, R., Stelmokaitis, G., Navickas, A.A., 2021. Natural zeolite powder in cementitious composites and its application as heavy metal absorbents. J. Build. Eng. 43, 103085 https://doi.org/10.1016/j.jobe.2021.103085.

Sabet, F.A., Libre, N.A., Shekarchi, M., 2013. Mechanical and durability properties of self consolidating high performance concrete incorporating natural zeolite, silica fume and fly ash. Constr. Build. Mater. 44, 175–184. https://doi.org/10.1016/j.conbuildmat.2013.02.069.

Salehi, H., Mazloom, M., 2019. An experimental investigation on fracture parameters and brittleness of self-compacting lightweight concrete containing magnetic field treated water. Arch. Civ. Mech. Eng. 19, 803–819. https://doi.org/10.1016/j.acme.2018.10.008.

Shafigh, P., Jumaat, M.Z., Mahmud, H.Bin, Hamid, N.A.A., 2012. Lightweight concrete made from crushed oil palm shell: Tensile strength and effect of initial curing on compressive strength. Constr. Build. Mater. 27, 252–258. https://doi.org/10.1016/j.conbuildmat.2011.07.051.

Sharma, H., Majeed, B., Sharma, S., 2020. Influence of nano-modification on strength parameters of concrete, Lecture Notes in Civil Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-13-7480-7_8.

Shi, C., Wu, Y., 2005. Mixture proportioning and properties of self-consolidating lightweight concrete containing glass powder. ACI Mater. J. 102, 355–363. https://doi.org/10.14359/14715.

Sonebi, M., Grünewald, S., Walraven, J., 2007. Filling ability and passing ability of self-consolidating concrete. ACI Mater. J. 104, 162–170. https://doi.org/10.14359/18579.

Spiesz, P., Yu, Q.L., Brouwers, H.J.H., 2013. Development of cement-based lightweight composites – Part 2: Durability-related properties. Cem. Concr. Compos. 44, 30–40. https://doi.org/10.1016/j.cemconcomp.2013.03.029.

Su, N., Wu, C., 2003. Effect of magnetic field treated water on mortar and concrete containing fly ash 25, 681–688. https://doi.org/10.1016/S0958-9465(02)00098-7.

Su, N., Wu, Y., Mar, C., 2000. Effect of magnetic water on the engineering properties of concrete containing granulated blast-furnace slag 30, 1–7.

Ting, T.Z.H., Rahman, M.E., Lau, H.H., 2020. Sustainable lightweight self-compacting concrete using oil palm shell and fly ash. Constr. Build. Mater. 264, 120590 https://doi.org/10.1016/j.conbuildmat.2020.120590.

Ting, T.Z.H., Rahman, M.E., Lau, H.H., Ting, M.Z.Y., 2019. Recent development and perspective of lightweight aggregates based self-compacting concrete. Constr. Build. Mater. 201, 763–777. https://doi.org/10.1016/j.conbuildmat.2018.12.128.

Tumidajski, P.J., Schumacher, A.S., Perron, S., Gu, P., Beaudoin, J.J., 1996. On the relationship between porosity and electrical resistivity in cementitious systems. Cem. Concr. Res. 26, 539–544. https://doi.org/10.1016/0008-8846(96)00017-8.

Vahabi, M.Y., Tahmouresi, B., Mosavi, H., Fakhretaha Aval, S., 2021. Effect of pre-coating lightweight aggregates on the self-compacting concrete. Struct. Concr. 1–12. https://doi.org/10.1002/suco.202000744.

Vossberg, C., Mason-Jones, K., Cohen, B., 2014. An energetic life cycle assessment of C&D waste and container glass recycling in Cape Town, South Africa. Resour. Conserv. Recycl. 88, 39–49. https://doi.org/10.1016/j.resconrec.2014.04.009.

Wu, Z., Zhang, X., Ma, Z., Li, X., Yu, R.C., 2021. Bond Behavior of Deformed Bars in Self-Compacting Lightweight Aggregate Concrete at Early Ages. J. Mater. Civ. Eng. 33, 04020460 https://doi.org/10.1061/(asce)mt.1943-5533.0003573.

Wu, Z., Zhang, Y., Zheng, J., Ding, Y., 2009. An experimental study on the workability of self-compacting lightweight concrete. Constr. Build. Mater. 23, 2087–2092. https://doi.org/10.1016/j.conbuildmat.2008.08.023.

Yang, S., Wang, L., 2017. Effect of Internal Curing on Characteristics of Self-Compacting Concrete by Using Fine and Coarse Lightweight Aggregates. J. Mater. Civ. Eng. 29, 04017186 https://doi.org/10.1061/(asce)mt.1943-5533.0002044.

Yang, S., Yue, X., Liu, X., Tong, Y., 2015. Properties of self-compacting lightweight concrete containing recycled plastic particles. Constr. Build. Mater. 84, 444–453. https://doi.org/10.1016/j.conbuildmat.2015.03.038.

Yashar, M., Behzad, V., 2021. Effect of pre-coating lightweight aggregates on the self-compacting concrete 1–12. https://doi.org/10.1002/suco.202000744.

Yim Wan, D.S.L., Aslani, F., Ma, G., 2018. Lightweight Self-Compacting Concrete Incorporating Perlite, Scoria, and Polystyrene Aggregates. J. Mater. Civ. Eng. 30, 04018178 https://doi.org/10.1061/(asce)mt.1943-5533.0002350.

Yu, Q.L., Spiesz, P., Brouwers, H.J.H., 2013. Development of cement-based lightweight composites – Part 1: Mix design methodology and hardened properties. Cem. Concr. Compos. 44, 17–29. https://doi.org/10.1016/j.cemconcomp.2013.03.030.

Yu, Z., Tang, R., Cao, P., Huang, Q., Xie, X., Shi, F., 2019. Multi-axial test and failure criterion analysis on self-compacting lightweight aggregate concrete. Constr. Build. Mater. 215, 786–798. https://doi.org/10.1016/j.conbuildmat.2019.04.236.

Zhang, J., Ma, G., Huang, Y., Aslani, F., Nener, B., 2019. Modelling uniaxial compressive strength of lightweight self-compacting concrete using random forest regression. Constr. Build. Mater. 210, 713–719. https://doi.org/10.1016/j.conbuildmat.2019.03.189.

Zhao, M., Zhang, B., Shang, P., Fu, Y., Zhang, X., Zhao, S., 2019. Complete stress-strain curves of self-compacting steel fiber reinforced expanded-shale lightweight concrete under uniaxial compression. Materials (Basel) 12. https://doi.org/10.3390/ma12182979.

Zhu, Y., Cui, H., Tang, W., 2016. Experimental investigation of the effect of manufactured sand and lightweight sand on the properties of fresh and hardened self-compacting lightweight concretes. Materials (Basel) 9. https://doi.org/10.3390/ma9090735.