

Enhancing mechanical and thermal performance of EPS lightweight concrete using condensed silica fume for sustainable building applications

Thanongsak Nochaiya^{*1, 2)}, Attakorn Thongtha¹⁾, Savanee Vanaleesin¹⁾, Panisara Disuea¹⁾, Aniruj Akkarapongtrakul^{1, 3)}, Pincha Torkittikul⁴⁾, Watcharapong Wongkeo⁵⁾ and Arnon chaipanich^{6, 7)}

¹⁾Department of Physics, Faculty of Science, Naresuan University, Phitsanulok 65000, Thailand

²⁾Research Center for Academic Excellence in Applied Physics, Naresuan University, Phitsanulok 65000, Thailand

³⁾Department of Royal Rain Making and Agricultural Aviation, Bangkok 10900, Thailand

⁴⁾Department of Civil Technology, Faculty of Industrial Technology, Lampang Rajabhat University, Lampang 52000, Thailand

⁵⁾Physics and General Science Program, Faculty of Science and Technology, Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima 30000, Thailand

⁶⁾Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

⁷⁾Center of Excellence in Materials Science and Technology, Chiang Mai University, Chiang Mai 50200, Thailand

Received 2 May 2025

Revised 9 July 2025

Accepted 20 October 2025

Abstract

Condensed silica fume (CSF), a highly reactive pozzolanic material, is produced as a by-product of silicon and ferrosilicon alloy manufacture. It is well known for its high silica content and ultra-fine particle size, which make it useful for improving the cement performance. The present study aims to investigate the impact of CSF on the properties of lightweight concrete composites (LWC). CSF was utilized to partially replace cement by up to 8 wt% in order to improve the strength properties of LWC. To produce LWC with a density of 800-900 kg/m³, recycled expanded polystyrene foam (re-EPS) was incorporated at 53 Vol% of the total LWC volume. Compressive strength, density, thermal conductivity, and time lag were investigated. The results indicated that the compressive strength of LWC blended with CSF increased significantly at early ages, while the density was notably lower than that of the control LWC. Although the thermal conductivity did not significantly change with increasing CSF content, all values remained within the acceptable range for insulating materials. In addition, the re-EPS lightweight concrete containing CSF demonstrated a longer time lag in heat transfer from the exterior to the interior of the building wall, which potentially improving energy efficiency for building applications.

Keywords: Lightweight concrete, Expanded polystyrene foam, Condensed silica fume, Time lag, Thermal conductivity

1. Introduction

Lightweight concrete (LWC) is widely used as a construction material due to their good thermal properties, low density, and fire resistance [1]. LWC can be classified based on its production method into no-fines concrete, aerated concrete, and lightweight aggregate concrete [2-4]. Generally, LWC is produced by mixing lightweight aggregate materials such as vermiculite, pumice, calcined diatomite [5], or an air-entraining agent in concrete. As well as, expanded polystyrene (EPS) is a well-established insulation material used in construction because it is a lightweight, rigid foam with excellent thermal insulating properties [6]. EPS foam is a cellular plastic consisting of spherical-shaped particles containing about 98% air, which is commonly used for packaging or thermal insulation [7]. According to a prior report, huge amounts of incorrectly graded EPS foam are produced as plastic waste during manufactures, estimated at over 32.7×10^9 kg/year annually worldwide [8]. When EPS waste decomposes, it forms microplastics (<5 mm) that include carcinogenic styrene monomers, which pose serious risks to aquatic organisms through accidental ingestion [9, 10]. Although EPS is beneficial for improving thermal insulation in lightweight concrete, its incorporation often leads to a reduction in mechanical strength, limiting its use in structural applications [7]. To address this limitation, recent studies have investigated the use of natural and industrial waste materials as aggregates or binders to enhance the performance of LWC [5, 11]. These materials not only improve mechanical strength but also contribute to the development of sustainable and thermally efficient lightweight concrete.

As well known, supplementary cementing materials (SCMs) are widely used in concrete production, which reduce water demand, enhance long-term strength and contributed durability [12-14]. Pozzolans are a category of SCMs such as fly ash, bottom ash, silica fume, palm oil fuel ash and natural pozzolans, which defines as a material composed of silica or silica and alumina components, in the presence of water, that react with calcium hydroxide to form cementitious materials [12]. Condensed silica fume (CSF), a highly reactive pozzolanic by-product from silicon and ferrosilicon alloy production, which contains over 85% amorphous silica [12, 15]. Typically, CSF consists of agglomerated particles with a spherical shape and a size of approximately 100 μm . Since its ultrafine particle size, the pozzolanic reaction of CSF is well known to increase the strength and durability [16, 17]. Several studies have reported that

*Corresponding author.

Email address: thanongsakno@nu.ac.th

<https://doi.org/10.64960/easr.2026.261970>

using CSF in small amounts can increase concrete strength by up to 170% [18] and also improve durability of concrete by refining the pore structures and promoting additional calcium silicate hydrate via pozzolanic reactions [19]. Moreover, the incorporation of CSF in alkali-activated mortars has been shown to enhance strength and chemical resistance, presenting its versatility in sustainable construction applications [20].

This research focuses on incorporating recycled materials, such as expanded polystyrene (EPS) foam, into lightweight (LWC), not only to divert plastic waste from landfills but also to contribute to the circular economy by reusing materials in buildings. Nevertheless, the relationship between the amount of CSF incorporated in EPS lightweight concrete and its resulting properties has not been well reported. Therefore, this study investigates the influence of CSF on the mechanical and thermal properties of EPS-based lightweight concrete. This research aims to enhance compressive strength, reduce thermal conductivity, and improve energy efficiency through increased time lag in heat transfer. The properties evaluated including compressive strength, density, thermal conductivity, and thermal time lag, which are critical parameters for assessing the suitability of LWC in sustainable building envelopes and thermally efficient wall systems.

2. Materials and methods

2.1 Raw materials

This study used Portland cement type I (PC) as the primary binder. Condensed silica fume (CSF), which was obtained from Sikament Co., Ltd., Thailand, was utilized as a partial cement substitute at up to 8wt%. The chemical composition of PC and CSF are presented in Table 1. River sand with a specific gravity of 2.65 was used as a fine aggregate. The recycled expanded polystyrene foam (re-EPS), a recyclable material in manufacturing classified as Politerm Economic Recycle grade, was obtained from Cebau Industries Co., Ltd., Thailand. The re-EPS foam used in this study had a specific gravity of 0.02, with varied shapes—predominantly spherical—and particle sizes ranging from 3 to 10 mm. It was used as a fine aggregate at 50 Vol% to produce lightweight concrete (LWC). The microstructure was analyzed using a scanning electron microscope (SEM; JOEL/Leo 1455VP) along with energy dispersive X-ray spectroscopy (EDS; AMETEK).

Table 1 Chemical compositions of Portland cement and CSF using EDS technique.

Sample	Element content (wt%)									LOI (%)
	Ca	O	Si	Al	C	P	K	Fe	Mg	
Cement	43.6	27.7	6.9	2.0	15.6	0.8	0.5	2.9	-	2.2
CSF	1.2	40.5	53.5	0.8	0.5	-	-	1.7	1.8	-

2.2 Sample preparation and test

The LWC mixtures were designed in accordance with the Thai Industrial Standard (TIS 2601-2013) for cellular lightweight concrete block using performed foam type C9. A compressive strength of over 25.5 kg/cm² and dried density of between 801 and 900 kg/m³ are required. The mix design and flows are given in Table 2, by fixing the water-to-binder (w/b) and sand-to-binder (s/b) ratios of 0.46 and 2.5, respectively. First, the binders were combined with sand and water to create a homogeneous mixture. The EPS foam was then added gradually to ensure uniformity. Remarkably, segregation may occur during the casting process since re-EPS foam has a lower density than water. This was accomplished by maintaining a flowability range of approximately 110 to 150 mm using a high-range water-reducing admixture.

For compressive strength and density testing, cube specimens of 10 cm × 10 cm × 10 cm was prepared. Flat samples (20 cm × 20 cm × 2 cm) were used to evaluate time lag and decrement factor. Additionally, cylindrical samples (4 cm diameter × 10 cm height) were cast for thermal conductivity testing. All LWC specimens were kept in molds for 24 hours, and then cured in saturated limewater until testing. Density were conducted following the standard test method ASTM C642 [21]. Compressive strength was performed using a compression machine with a loading rate of 1.2 kN/s. For thermal analysis, the specimens were oven-dried at 60 °C for 72 hours, and then stored at room temperature for 24 hours before testing. The thermal conductivity was evaluated at using a KD2 PRO Thermal Properties Analyser.

Table 2 Mixture design of the EPS-CSF lightweight concrete.

Mix	Mix proportions of EPS concrete (kg/m ³)						Flow (mm)
	PC	CSF	water	sand	EPS	Superplasticizer	
PC	436	0	202	353	10	2	141
CSF2	426	9	202	352	10	2	130
CSF4	417	17	202	352	10	2	121
CSF6	408	26	202	351	10	2	114
CSF8	399	35	201	351	10	2	113

2.3 Time lag and decrement factor test

The time lag, which is the delay in heat transfer from the exterior to interior through lightweight concrete (LWC), was analyzed in a laboratory setup using a thermal sensor (DS1820) connected to an Arduino UNO. The experimental setup is illustrated in Figure 1a. A steel plate (Room 1) was heated by a 100 W halogen lamp for continuous heat transfer to the LWC sample. Temperature sensors were positioned as shown in Figure 1a. Before testing, the LWC sample was oven-dried at 110±5 °C for 24 hours and allowed to cool in air to room temperature. During testing, the steel surface temperature was kept at 70°C by adjusting the heat source for temperature uniformity. After that, the halogen lamp was turned off for 1.5 hours, allowed to cool, and then turned back on. Each sample was evaluated five test cycles using a data logger. Figure 1b illustrates the relationship between temperature and time. The time difference

between the highest temperature on the outer surface ($t_{e,max}$) and the inner surface ($t_{i,max}$), as shown by Eq. (1), was used to calculate the time lag (ϕ). The decrement factor (f) was calculated by Eq. (2), which represents the attenuation of temperature between the exterior and interior surfaces, where A_i and A_e are the amplitudes of temperature fluctuations on the inner and outer surfaces, respectively. Furthermore, measurements were taken of the outside surface's maximum temperature ($T_{e,max}$) and its minimum temperature ($T_{e,min}$) as well as the internal surface's maximum temperature ($T_{i,max}$) its minimum temperature ($T_{i,min}$). The heat gain time (τ) was computed by Eq. (3), representing the amount of time required for heat transfer to reach the outside surface's maximum temperature. This was calculated by using the times of the exterior surface's maximum ($t_{e,max}$) and minimum ($t_{e,min}$) temperatures [22].

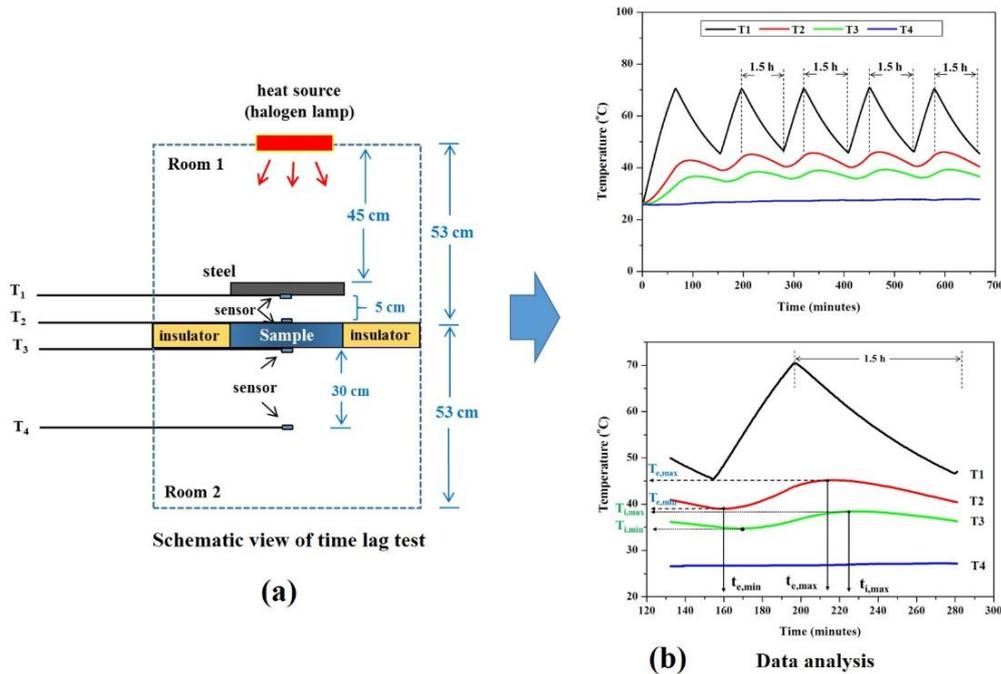


Figure 1 (a) Schematic representation of time lag testing apparatus and (b) the time lag analysis (T1, T2, T3 and T4 represent the temperature of the steel surface, the upper sample surface, the bottom sample surface, and inside Room 2, respectively, as indicated by the sensor positions shown in Figure 1a).

$$\text{Time lag } (\phi) = t_{e,max} - t_{i,max} \quad (1)$$

$$\text{Decrement factor } (f) = \frac{A_i}{A_e} = \frac{T_{e,max} - T_{e,min}}{T_{i,max} - T_{i,min}} \quad (2)$$

$$\text{Heat gain time } (\tau) = t_{e,max} - t_{e,min} \quad (3)$$

3. Results and discussion

3.1 Microstructure

The microstructure of the EPS-CSF lightweight concrete is depicted in Figures 2. In the PC mix, the microstructure of the cement paste presents a dense matrix, whereas the EPS foam exhibits a porous matrix that resembles a honeycomb (Figure 2a). Furthermore, calcium silicate hydrate phases (needle-like or fiber-like) are visible at the interface between the cement paste and EPS foam, and also insert into the EPS matrix's pores. Although cement particles cannot penetrate the closed-cell matrix of the re-EPS foam, there appears to be a strong bond at the interface of both matrices. Figure 2b also shows the microstructure of the EPS-CSF lightweight concrete. It was found that CSF particles filled the cement paste matrix. Similar to the control mix, the cement matrix not only filled the EPS foam but also exhibited a dense interface with hydration products. According to a previous study [19], the significant pozzolanic activity of CSF improves the microstructure of cement paste. The formation of CSH gel, which is the product of the reaction between CSF and $\text{Ca}(\text{OH})_2$ during hydration in an alkaline environment, reveals this binding activity. The resulting CSH gel fills voids and decreases the porosity of cementitious matrix.

3.2 Compressive strength

The compressive strength and relative compressive strength of EPS lightweight concrete are presented in Figure 3. For all mixtures, the compressive strength of the EPS-CSF lightweight concrete was found to increase with increasing curing time. Notably, as compared to the control (PC mix), the LWC with CSF exhibited a greater compressive strength. In particular, the mix containing 8wt% CSF was found to be the highest compressive strength (Figure 3a). This is attributed to the dual effects of CSF particles acting as fillers and the pozzolanic reaction, which increases the formation of calcium silicate hydrate phase (C-S-H) and thereby enhances the compressive strength of the concrete [23-25]. These results are consistent with prior studies that adding CSF significantly enhances the compressive strength of mortar and concrete [25]. Moreover, the degree of hydration and pozzolanic reactions was assessed using the relative compressive strength comparing to the control concrete (Figure 3b). It can be observed that all mixes containing CSF demonstrated relative strengths exceeding 100%, especially the CSF8 mix having the highest strength at up to 136% for 3 days and 123% for 28

days. Previous researches have suggested the use of 10wt% CSF as an additive, which improves the strength [13, 17] and durability [25-27] of the concrete. These findings demonstrate that CSF can significantly improve the mechanical properties of EPS lightweight concrete.

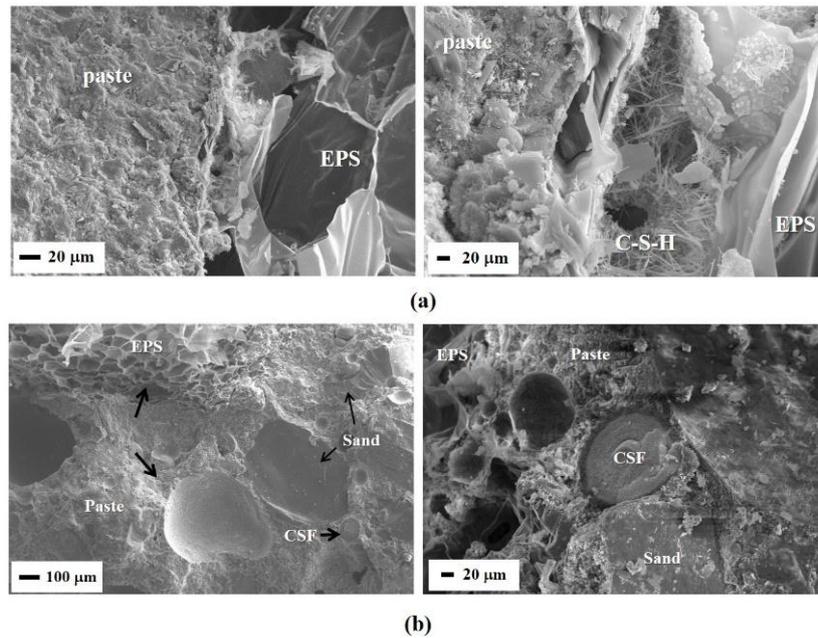


Figure 2 Microstructure of the lightweight concrete after curing at 28 days; (a) the PC lightweight concrete and (b) the EPS-CSF lightweight concrete.

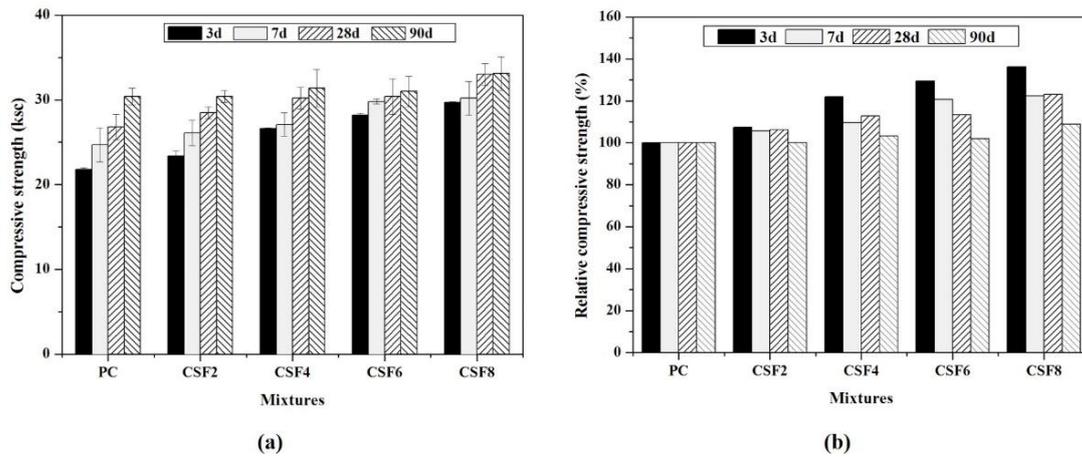


Figure 3 (a) Compressive strength and (b) relative compressive strength of EPS lightweight concrete with CSF of 0-8 wt% after curing at 3, 7, 28 and 90 days.

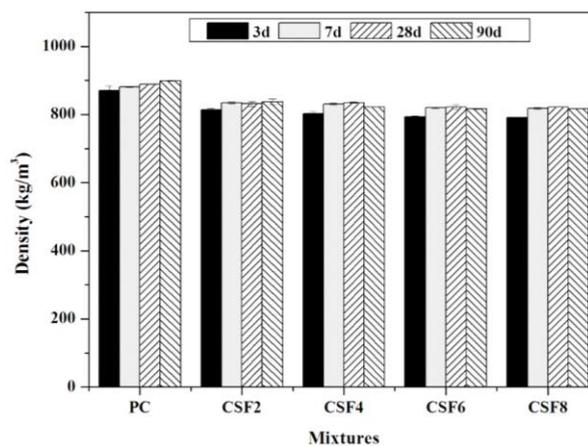


Figure 4 Density of LWC with CSF of 0-8 wt% after curing at 3, 7, 28 and 90 days.

3.3 Density

Figure 4 represents the density of EPS-CSF lightweight concrete after curing at 3, 7, 28 and 90 days. The density of the control concrete was 870-900 kg/m³, which is comparatively higher than that of the EPS-CSF lightweight concretes (790-840 kg/m³). A decrease in density was observed, when the amount of CSF increased. This finding may be due to the different specific gravities of the concrete components (cement and CSF of 3.15 and 2.2, respectively [12]), which result in a decrease in the density of the EPS lightweight concrete. Moreover, all mixes represented a slight increase in density as curing times increased. However, the densities of all mixtures conformed to the Thai Industrial Standard (TIS. 1505-2541) for air-entranced lightweight concrete block types C8 and C9, with dried density of between 701 and 900 kg/m³.

3.4 Thermal properties

The time lag (ϕ), decrement factor (f), and heat gain time (τ) of the EPS-CSF lightweight concrete at 28 days and 90 days are shown in Table 3. The time lag and decrement factor are key factors that affect the thermal performance of the lightweight concrete. The time lag is the time of heat wave takes to move from the exterior surface to the interior surface, while the declining ratio in the temperature amplitude is known as the decrement factor [22, 28]. The EPS lightweight concrete presented a slightly decreased in decrement factor with increasing curing time. Moreover, there was no discernible difference in the decrement factor of the LWC when the CSF concentration increased. Regarding, it was found that the time lag of PC mix decreased as the curing time increased. This trend was also evident in the EPS lightweight concrete containing CSF. The CSF8 mix showed the greatest time lag, with values of 14.9 minutes for 28 days and 13.2 minutes for 90 days. Additionally, the time lag of the CSF8 mix was higher than that of the PC mix, with relative time lag of 132% at 28 days and 131% at 90 days. These findings suggest that increasing the CSF in LWC improves its insulating properties. Notably, the CSF8 mix demonstrates optimal performance by significantly extending the heat wave propagation time from the outer to the inner surface. This extended delay not only reduces peak indoor temperatures but also contributes to lower energy demand for cooling.

The heat gain time of the EPS lightweight concrete containing CSF cured at 28 and 90 days is presented in Table 3. This value demonstrates the heat accumulation time on the exterior surface of the samples, from the minimum to the maximum temperature. The results show that the heat gain time of the PC mix was 62.0 minutes at 28 days and 55.4 minutes at 90 days, while the heat gain times of the EPS-CSF lightweight concrete ranged from 57.8 to 58.9 minutes at 28 days and from 50.6 to 54.2 minutes at 90 days. It is noticeable that the EPS-CSF lightweight concrete had a shorter heat gain time than the PC mix. Furthermore, the heat gain time of all mixtures decreased when the curing time increased.

Table 3 Decrement factor, time lag and heat gain time of the EPS-CSF lightweight concrete.

Mix	f		ϕ (min)		τ (min)	
	28 days	90 days	28 days	90 days	28 days	90 days
PC	0.554	0.516	11.3	10.2	62.2	55.4
CSF2	0.602	0.601	12.9	11.3	58.9	54.2
CSF4	0.579	0.554	13.4	12.7	58.9	52.3
CSF6	0.564	0.551	14.4	12.7	58.2	51.9
CSF8	0.573	0.548	14.9	13.3	57.8	50.6

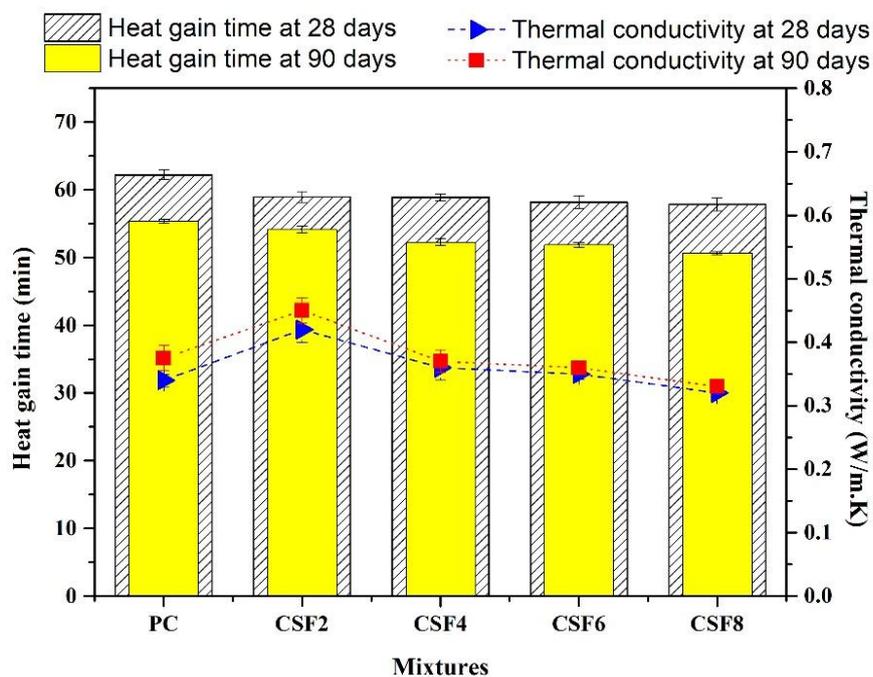


Figure 5 Heat gain time and thermal conductivity of EPS-CSF lightweight concrete.

For additional investigation, the thermal conductivity of the EPS-CSF lightweight concrete at 28 and 90 days is presented in Figure 5. The control lightweight concrete mix (PC mix) had a thermal conductivity of approximately 0.33-0.37 W/m-K, while the EPS-CSF lightweight concrete mixes showed values between 0.32 and 0.46 W/m-K. The obtained thermal conductivity values were slightly lower than those reported in previous research [11], but remained close to the value specified for insulating lightweight concrete (AAC brick) in the ASTM C332-17 standard [29]. Moreover, it was observed that the thermal conductivity of all mixtures at 28 days was lower than that at 90 days. Extended curing times generally lead to increased cement hydration and the formation of hydration products that fill the voids between cement particles [13, 19]. Although, the CSF2 mixture exhibited a slight increase in thermal conductivity, no statistically significant differences were observed with further additions of CSF from 4 to 8 wt%. This result may be attributed to the microstructural refinement achieved at 2 wt% CSF, which reduces the number of micropores and enhances matrix densification in the cement paste, thereby improving the continuity of the solid thermal pathway). In contrast, higher CSF contents may promote particle agglomeration, leading to increased heterogeneity and the formation of larger pores. However, it is suggested that macro-pores in the range over 50 μm within the cement matrix exert a significant influence on the thermal conductivity of concrete [30]. Additionally, the presence of macro-pores introduced by re-EPS had a greater impact on the thermal conductivity of the lightweight concrete than the relative volume fraction of the CSF additive. This is evident from the volumetric proportions used in the mix design, where CSF constitutes only approximately 2 vol% (at 8wt% replacement), compared to 53 vol% for re-EPS. However, prior research [22] has noted that decreasing the thermal conductivity of envelope materials is crucial for reducing heat transmission loads and achieving energy-saving goals.

4. Conclusions

The incorporation of condensed silica fume (CSF) as a partial replacement for Portland cement in recycled expanded polystyrene (re-EPS) lightweight concrete demonstrated significant improvements in both mechanical and thermal performance. The enhanced compressive strength, particularly at early ages, was attributed to the pozzolanic reaction and filler effect of CSF, while the slight reduction in density remained within the Thai Industrial Standard for lightweight concrete (classified as C8 and C9). Although the additional of CSF did not significantly reduce the thermal conductivity of EPS lightweight concrete, the values remained within the acceptable range for insulating materials and close to the ASTM standard for ACC bricks. Furthermore, a higher CSF content resulted in a longer time lag with no significantly change in a decrement factor, suggesting improved thermal resistance and potential for energy saving. Consequently, these findings support the usage of CSF as a sustainable additive for producing high-performance lightweight concrete with enhanced structural strength and thermal properties, promoting its application in environmentally friendly and energy-efficient construction.

5. Acknowledgements

The authors would like to express their sincere gratitude to Thailand Science Research and Innovation (TSRI) through Naresuan University for financial support under the Fundamental Fund 2025 (Grant No. R2568B025). Additional support from the Global and Frontier Research University Fund, Naresuan University (Grant No.2567C001), is also gratefully acknowledged.

6. References

- [1] Sulong NHR, Mustapa SAS, Rashid MKA. Application of expanded polystyrene (EPS) in buildings and constructions: a review. *J Appl Polym Sci.* 2019;136(20):1-11.
- [2] Mindess S, Young JF, Darwin D. *Concrete*. 2nd ed. Upper Saddle River: Pearson Education; 2003.
- [3] Libre NA, Shekarchi M, Mahoutian M, Soroushian P. Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice. *Constr Build Mater.* 2011;25(5):2458-64.
- [4] Muralitharan RS, Ramasamy V. Development of lightweight concrete for structural applications. *J Struct Eng.* 2017;44:1-5.
- [5] Posi P, Lertnimoolchai S, Sata V, Phoo-ngernkham T, Chindaprasirt P. Investigation of properties of lightweight concrete with calcined diatomite aggregate. *KSCE J Civ Eng.* 2014;18(5):1429-35.
- [6] Zhihua P, Hiromi F, Tionghuan W. Preparation of high performance foamed concrete from cement, sand and mineral admixtures. *J Wuhan Univ Technol.* 2007;22:295-8.
- [7] González-Betancur D, Hoyos-Montilla AA, Tobón JI. Sustainable hybrid lightweight aggregate concrete using recycled expanded polystyrene. *Materials.* 2024;17(10):2368.
- [8] Lithner D, Larsson Å, Dave G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Sci Total Environ.* 2011;409(18):3309-24.
- [9] Galloway TS, Cole M, Lewis C. Interactions of microplastic debris throughout the marine ecosystem. *Nat Ecol Evol.* 2017;1:116.
- [10] Steer M, Cole M, Thompson RC, Lindeque PK. Microplastic ingestion in fish larvae in the western English Channel. *Environ Pollut.* 2017;226:250-9.
- [11] Detphan S, Phiangphimai C, Wachum A, Hanjitsuwan S, Phoo-ngernkham T, Chindaprasirt P. Strength development and thermal conductivity of POFA lightweight geopolymer concrete incorporating FA and PC. *Eng Appl Sci Res.* 2021;48(6):718-23.
- [12] Thomas M. *Supplementary cementing materials in concrete*. USA: Taylor & Francis; 2003.
- [13] Chaipanich A, Nochaiya T. Thermal analysis and microstructure of Portland-cement-fly ash-silica fume pastes. *J Therm Anal Calorim.* 2010;99:487-93.
- [14] Kiattikomol K, Jaturapitukkul C, Songpiriyakij S, Chutubtim S. A study of ground coarse fly ashes with different fineness from various sources as pozzolanic materials. *Cem Concr Compos.* 2001;23(4-5):335-43.
- [15] Kirkbride TW. *Condensed silica fume in concrete*. London: Thomas Telford; 1988.
- [16] Nochaiya T, Jeenram T, Disuea P, Tortittikul P. Microstructure, compressive strength, and permeability of Portland-condensed silica fume cement. *Monatsh Chem.* 2017;148:1363-70.
- [17] Nochaiya T, Wongkeo W, Chaipanich A. Utilization of fly ash with silica fume and properties of Portland cement-fly ash-silica fume concrete. *Fuel.* 2010;89(3):768-74.
- [18] Fallah S, Nematzadeh M. Mechanical properties and durability of high-strength concrete containing macro-polymeric and polypropylene fibers with nano-silica and silica fume. *Constr Build Mater.* 2017;132:170-87.

- [19] Smarzewski P. Mechanical and microstructural studies of high-performance concrete with condensed silica fume. *Appl Sci.* 2023;13(4):2510.
- [20] Sothornchaiwit K, Dokdua W, Tangchirapat W, Keawsawasvong S, Thongchom C, Jaturapitakkul C. Influences of silica fume on compressive strength and chemical resistances of high calcium fly ash-based alkali-activated mortar. *Sustainability.* 2022;14:2652.
- [21] ASTM. ASTM C642-06: Standard test method for density, absorption, and voids in hardened concrete. Philadelphia: ASTM International; 2006.
- [22] Thongtha A, Maneewan S, Punlek C, Ungkoon Y. Investigation of the compressive strength, time lag and decrement factors of AAC-lightweight concrete containing sugar sediment waste. *Energy Build.* 2014;84:516-25.
- [23] Somma R, Jaturapitakkul C, Rattanachu P, Chalee W. Effect of ground bagasse ash on mechanical and durability properties of recycled aggregate concrete. *Mater Des.* 2012;36:597-603.
- [24] Bapat JD. Mineral admixtures in cement and concrete. USA: Taylor & Francis; 2013.
- [25] Zhang Z, Zhang B, Yan P. Hydration and microstructures of concrete containing raw or densified silica fume at different curing temperatures. *Constr Build Mater.* 2016;121:483-90.
- [26] Demirboga R. Thermal conductivity and compressive strength of concrete incorporation with mineral admixtures. *Build Environ.* 2007;42(7):2467-71.
- [27] Wongkeo W, Thongsanitgarn P, Ngamjarrojana A, Chaipanich A. Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume. *Mater Des.* 2014;64:261-9.
- [28] Ng SC, Low KS, Tioh NH. Newspaper sandwiched aerated lightweight concrete wall panels—thermal inertia, transient thermal behavior and surface temperature prediction. *Energy Build.* 2011;43(7):1636-45.
- [29] ASTM. ASTM C332-17: Standard specification for lightweight aggregates for insulating concrete. West Conshohocken: ASTM International; 2017.
- [30] Sarkar PK, Mitra N. Thermal conductivity of cement paste: influence of macro-porosity. *Cem Concr Res.* 2021;143:106385.