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Drying Shrinkage and Moisture Loss of Lightweight Concrete mixed with Fine Recycled Concrete Aggregate (FRCA)

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Abstract

The paper reports on drying shrinkage and moisture loss of lightweight concrete exposed to the natural laboratory environment. Concrete was designed using fine recycled concrete aggregate, sand, cement, silica fume, foaming agent and water. Four mixed designs were utilized. The quantity of silica fume used to replace cement was about 10% (by weight of cement). Meanwhile, fine recycled concrete aggregate (FRCA) was used to replace sand from 0% to 30% by weight of sand. Three specimens (300mm x 75mm x 75mm) were cast for each mix and cured for one day. Specimens were measured for shrinkage and moisture loss. The duration of the test was 28 days. Findings from this study show that all the lightweight foam concrete used in this study shrinks in a fluctuating trend when exposed to a natural laboratory environment. The concrete mixed with 20% and 30% of FRCA had the highest and lowest shrinkage values at 28 days, respectively. For every concrete mix, the trend of moisture loss is quite consistent. The concrete with 20% FRCA experienced the largest percentage of moisture loss, which supports the cause of the highest shrinkage strain. Conversely, concrete containing 30% FRCA exhibits the best link between drying shrinkage and moisture loss.

Keywords: Shrinkage**,** Lightweight concrete, Recycled aggregate, Drying shrinkage, Moisture content.

1. Introduction

Concrete is one of the most crucial materials acquired for any construction project. As a result, the need for concrete in the building industry has increased dramatically. Normal concrete (NC), lightweight concrete (LWC), and self-compacting concrete (SCC) are well-known for their application in the industry and offer their benefit. LWC is desired for its low density (Muralitharan & Ramasamy, 2017) and hence significantly lighter than the other two types of concrete. It promotes an easier construction process. LWC can also be used as walls for thermal insulation or as load transfer with the lowest density, depending on the motive it was created (Šeputytė-Jucikė et al., 2023). Due to its properties, LWC is also widely used to manufacture cast components such as wall panels, slabs, and blocks. Lightweight foamed concrete (LWFC) is a subtype of LWC. Meanwhile, foam concrete (FC) is a type of concrete with enclosed air voids to reduce its self-weight (Amran et al., 2020). The lightweight characteristics are caused by introducing air bubbles using a suitable foaming agent to the concrete mixture (Gökçe & Şenol Şeker, 2020) and could achieve a density of 400 to 1400 kg (Kozłowski & Kadela, 2018). This concrete has more than 20% air by volume and is a highly air-entrained sand cement or sometimes can be cement-only slurry. As a result, this type of concrete flows easily, can be self-compacting, and has excellent insulation properties.

LWFC requires fewer natural resources in its composition and offers superior fire resistance, low weight, and good thermal insulation because of the matrix's air void system (Dudhe et al., 2024). As a result, LWC offers more environmentally friendly concrete than normal concrete. Hence, it is often utilized as an insulation structure in construction projects such as walls, roofs, and floors. Sometimes, LWFC may be used as a substitute for normal concrete in the non-structural part of the project due to its minimal weight, creating less dead load imposed on the structure. However, the extensive use of sand in rapid concrete construction causes environmental health problems (Huang et al., 2018; Mostafaei et al., 2023), such as erosion, flooding, salination of aquifers and collapse of coastal defences. Reducing carbon emissions from conventional cement materials, especially Ordinary Portland Cement (OPC), continues to be a significant environmental challenge (Zhang et al., 2015). As a result, numerous studies have been conducted to partially replace cement without reducing the quality of the concrete. Therefore, supplementary cementitious materials (SCM) such as silica fume (SF), fly ash (FA), rice husk ash (RHA), and ground granulated blast furnace slag (GGBS) (Qureshi et al., 2020). have been introduced as cement partial replacement. However, adding a large amount of supplementary cementitious materials (SCM) to the LWFC could also deteriorate the integrity of the lightweight concrete due to the formation of more air spaces in the mortar slurry which increases the porosity, water absorption, and shrinkage of the concrete (Mat Serudin et al., 2020).

On the other hand, concrete experiences drying shrinkage throughout its life. Shrinkage is a complex process influenced by various factors, such as the concrete's constituents, environmental temperature and humidity, the age at which the concrete is exposed to drying conditions, and the size of the structural element (Barr et al., 2003). Drying shrinkage is the reduction in concrete volume caused by water loss during the drying process. Using foam in LWC to produce LWFC may increase the drying shrinkage strain as there are no coarse aggregates in the mix (Kunhanandan & Ramamurthy, 2009; Maghfouri et al., 2022). Meanwhile, shrinkage deformations of concrete are influenced by the number and quantity of materials used, such as slag, fly ash, superplasticizer, water-binder ratio (Hu et al., 2017), slag and metakaolin (Cheng et al., 2017) in the concrete mix. Moreover, foam in the LWC can cause drying shrinkage 10 times that observed on normal concrete due to a change in mineralogical compositions (Rai & Kumar, 2017). The interaction between cementitious pastes and precast foam determines the performance of the LWFC, which is controlled by the size and distribution of the pores (Mydin, 2023).

Despite the advantages offered by lightweight foamed concrete (LWFC), the phenomenon of shrinkage remains poorly understood (Kovler & Zhutovsky, 2006). This is primarily because shrinkage deformation is highly dependent on the type and content of the aggregates used (Luo et al., 2024), as well as the water content of the mix (Zhou et al., 2024). Insufficient water content can lead to poor fluidity and inadequate compaction (Jierula et al., 2024). In the present study, LWFC was produced using 10% silica fume (SF) as a partial cement replacement, 0% to 30% fine recycled concrete aggregate (FRCA) as a sand replacement, and a fixed water content across all mixes. FRCA typically contributes to increased early-age drying shrinkage due to its high-water absorption capacity and porous structure, which often necessitate a higher water demand. Therefore, this study offers a new and significant insight into the shrinkage behaviour of lightweight concrete incorporating fine recycled concrete aggregates under environmental exposure conditions. The primary objectives are to evaluate the drying shrinkage and moisture loss of LWFC, and to examine the relationship between these two parameters.

2. Review

The main materials used to produce LWFC in the current study are ordinary Portland cement (OPC), silica fume (SF), foaming agent, natural sand, and fine recycled concrete aggregates (FRCA). Hence, only these materials are reviewed in this section. Cement is an ingredient of concrete and can be considered the ‘glue’ that binds aggregates together to form concrete (Gagg, 2014). Silica fume or micro silica is a by-product of the ferrosilicon manufacturing process which is collected from exhaust gases by condensers. The colour of silica fume is either grey or white, and its size is much smaller than the average size of cement particles (Talib et al., 2019). Silica fume is used in concrete to improve its properties, such as compressive strength, bond strength, abrasion resistance and permeability of concrete. These properties help to protect reinforcing steel from corrosion (Talib et al., 2019; Khan & Siddique, 2011). Despite the advantages of using SF in concrete, SF has disrupted the environment and caused health problems because of its fineness and widespread availability as it can be easily blown by the wind.

On the other hand, the foaming agent plays a critical role in producing foamed concrete or lightweight foamed concrete as it is designed to create stable bubbles that simulate air voids in the concrete (Gökçe & Şenol Şeker, 2020). The demand for natural sand in Malaysia has been increasing with the rapid construction process, which has eventually caused a depletion in natural resources. The removal of river sand degrades the environment globally by changing the path of the water, eroding the shoreline, and producing pits and dead ends (Nedeljković et al., 2021). Thus, many researchers have been researching to find a suitable material that can replace the use of sand in concrete.

OPC plays a significant role in construction and speeds up the building process because of its quick setting and hardening. This hardening process continues for years implying that concrete gets stronger as it gets older (Gagg, C. R. (2014). Despite the advantages offered by cement, this material also contributes to the shrinkage deformation of concrete. Finer cement exhibits a larger total drying shrinkage (Maruyama, 2022). Meanwhile, the strength, fineness and composition of the cement are related to each other (Alexander, 1972). Table 1 demonstrates the chemical composition while Table 2 presents the mineral composition of OPC based on the percentage by weight (Li, 2023).

Table 1. Chemical Composition of OPC (Li, 2023).

No	Chemical Composition	Amount (%) by weight
1	Silicon Dioxide (SiO2)	21.65
2	Aluminium Oxide (Al2O3)	9.15
3	Sodium Oxide (Na2O)	0.24
4	Potassium Oxide (K2O)	0.66
5	Magnesium Oxide (MgO)	4.09
6	Calcium Oxide (CaO)	54.06
7	Ferum (III) Oxide (Fe2O3)	2.85
8	Sulphur Trioxide (SO3)	2.85
9	Titanium Dioxide (TiO2)	0.49
10	Loss on Ignition (L.O.I)	1.96

Table 2. Mineral Composition of OPC (Li, 2023).

No	Mineral Composition	Amount (%) by weight
1	Tricalcium Silicate (C_3S)	57.32
2	Dicalcium Silicate (C_2S)	23.51
3	Tricalcium Aluminate (C_3A)	6.48
4	Tetracalcium Aluminoferrite (C_4AF)	10.51
5	Rest	2.19

SF is made up of spherical particles with a high surface area that is incredibly small, usually with an average diameter of 0.1 to 0.3 micrometres (Jain & Sancheti, 2023). SF acts as the micro filler in the concrete as it fills up all the gaps between the cement particles (Shelote, 2023). As a result, the concrete matrix becomes denser, decreasing the porosity of the concrete and hence, is expected to lessen the drying shrinkage by reducing the volume changes brought on by moisture loss throughout the drying process. In contrast, greater drying shrinkage

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was obtained in foamed concrete with a higher density (Kadela, 2020) due to the complex phenomenon of drying shrinkage. The development of compressive strength in SF concrete is primarily influenced by the amount and characteristics of SF used and the curing period of the concrete (Shelote, 2023). The advantages offered by SF are provided by the pozzolanic properties of its chemical composition (Jain & Sancheti, 2023) as shown in Table 3.

Table 3. Chemical Composition of SF (Jain & Sancheti, 2023).

No	Mineral Composition	Amount (%) by weight
1	Silicon Dioxide (SiO_2)	92.31
2	Aluminium Oxide (Al_2O_3)	1.38
3	Magnesium Oxide (MgO)	0.37
4	Calcium Oxide (CaO)	3.15
5	Ferum (III) Oxide (Fe_2O_3)	-
6	Other	2.59
7	Loss on Ignition	0.2

Foaming agents used in the production of lightweight concrete are classified as synthetic, plant or animal glue/blood-based surfactants (Siva et al., 2017). The use of foams introduces air pores that will occupy 10% to 90% volume of hardened concrete, which subsequently affects the mechanical properties, durability, and thermal conductivity of the concrete (Hou et al., 2021). The characteristics of the foam influence the pore structure of foamed concrete (Xiong et al., 2023) and have a significant effect on the concrete properties (Kadela et al., 2020). In addition, the effectiveness of foam depends on the dilution of the foaming agent (Amran et al., 2020) and the mixing time to produce air pores (Amran, 2015). There are two most common methods of mixing which are high-speed mixing (in-mixed foaming) and compressed air mixing (pre-foamed) (Panesar, 2013).

Sand plays a significant role in creating a well-balanced concrete mixture that is durable and workable. However, the silt and clay content in the sand should be less than 10% according to ASTM C117 so as not to affect the strength of the concrete (Gashahun, A. D., 2020). River sand is a type of natural sand that is frequently utilized in producing concrete. It comprises tiny, spherical grains and fine particles (Gashahun, A. D., 2020). River sand typically has irregular, angular-shaped particles, and this shape strengthens its binding with coarse aggregate and cement paste (Ngugi, 2014). The colour of sand changes from darker to lighter when the amounts of ferum (Fe2O3 and aluminium (Al2O3) are smaller due to an increase in the silica (SiO2) content, and the increase of silica enhances the concrete strength (Gashahun, A. D., 2020). The quality of sand has a significant impact on how much concrete shrinks (Zhang, 2013). The concrete matrix can be packed more efficiently and have fewer voids by using well-graded aggregates in a variety of particle sizes, which may reduce the value shrinkage of the concrete. Table 4 presents the chemical composition of sand (Jain & Sancheti, 2023).

Table 4. Chemical Composition of Sand (Jain & Sancheti, 2023).

Component	Amount by weight (%)
Silicon Dioxide (SiO_2)	96.89
Aluminium Oxide (Al_2O_3)	1.47
Magnesium Oxide (MgO)	0.07
Calcium Oxide (CaO)	0.02
Ferum (III) Oxide (Fe_2O_3)	1.15
Other	0.4
Loss on Ignition	-

Small-sized crushed and processed concrete particles are referred to as fine recycled concrete aggregate (FRCA) and are used in place of natural sand in concrete mixtures. The waste concrete, usually obtained from construction sites, demolition sites, or abandoned buildings, is crushed and processed to create these used aggregates (Nedeljković et al., 2021). The goal of using leftover concrete is to support environmentally friendly

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building techniques. The physical properties, chemical properties, and water absorption of FRCA may vary depending on the original types of concrete used (Nedeljković et al., 2021). The moisture content of FRCA may be higher than that of natural aggregates because of the porosity of the binder and interfaces. The workability and moisture content of the concrete mix could be impacted by the water absorbed by FRCA, which can also alter the total water requirement of the mix. The high-water demand by FRCA may lead to an increase in the value of drying shrinkage due to the presence of old mortar (Nedeljković et al., 2021).

Recent studies demonstrate various results. Whitening et al. (2024) finds that the use of recycled aggregates increases drying shrinkage, highlighting the influence of aggregate properties and mix design on shrinkage deformation. This finding is supported by Wei et al. (2024) which investigated the use of lightweight aggregate in foamed concrete. Their experiments on shrinkage demonstrated that increasing the foam volume and incorporating lightweight aggregate resulted in greater drying shrinkage. They concluded that the overall deformation of the concrete was primarily attributed to the deformation of the lightweight aggregate itself, which was caused by its high porosity and low stiffness. Meanwhile, Luo et al. (2025) emphasizes that the water-to-cement ratio used significantly influence the shrinkage deformation.

Not many studies report specific shrinkage values. However, Lo et al. (2008) conducted a study on lightweight concrete with design strengths of 25 and 35 N/mm². The total shrinkage measured was 320×10^{-6} for the 25 N/mm² mix and 415×10^{-6} for the 35 N/mm² mix. Aziz et al. (2022) developed four types of concrete mixes. In the first three, normal weight aggregate (NWA) was replaced with 0%, 50%, and 100% coarse coconut shell (CS), respectively. In the fourth mix, equal quantities of NWA and CS were used, and 25% of the cement was replaced with bagasse ash. Their results showed that the shrinkage ranged from approximately 200 to 450 microstrain at 28 days, and from 400 to 600 microstrain at 200 days.

3. Research Method

The mix design of lightweight foamed concrete (LWFC) was determined using the Foamed Concrete Mix Design Spreadsheet. In this study, the target density of the LWFC ranged from 1300 kg/m³ to 1800 kg/m³. A fixed proportion of silica fume (SF), equivalent to 10% replacement of cement by weight, was used in all mixes. Four concrete mixtures were prepared, each incorporating the specified amount of SF and foaming agent. The foaming agent was used to generate stable foam essential for producing LWFC. For this purpose, Meyco SLF 30, a synthetic-based foaming agent supplied in 20-liter containers by LCM Sdn Bhd, was employed. The recommended mixing ratio of Meyco SLF 30 to water was maintained at 1:20. The quantity of foaming agent was determined based on the mix design requirements. The foaming agent and water were thoroughly blended using a mortar mixer for 10 to 15 minutes to produce stable foam, as shown in Figure 1. Based on practical experience, the foam was considered stable if it remained intact on the palm for a few seconds.

Figure 1. Foam.

Information on the concrete samples and tests is given in Table 5. Three (3) numbers of prisms were moulded from each mixture to be used throughout the testing duration. Table 6 demonstrates the final mix design used, but the quantity of the foaming agent is not presented.

Table 5. Test Characteristics.

Type of test	Test Standard	Type of sample	Concrete age at testing (days)
Drying shrinkage Moisture content	ASTM C157 ASTM C566	Prism (3 numbers) [300mm x 75mm x 75mm]	1, 2, 3, 4, 5, 6, 7, 14, 28

Table 6. Final Mix Design.

Mixture	Cement (kg)	Water (kg)	Silica fume (kg)	FRCA (kg)
LFC00FRCA	2.92	1.62	0.32	0.00
LFC10FRCA	2.92	1.62	0.32	0.49
LFC20FRCA	2.92	1.62	0.32	0.97
LFC30FRCA	2.92	1.62	0.32	1.46

Figure 2 shows the concrete specimens in the moulds (left) and in the water for curing (right). Procedures of mixing, casting, and curing were conducted in the laboratory. Although the duration of curing time may affect the early drying shrinkage but the effect on the total drying shrinkage is limited (Yang et al., 2017). Therefore, to replicate site conditions where formwork is removed after one day, the concrete in this study was cured for only one day. The specimens were left in the natural laboratory environment after curing until day 28. Figure 3 demonstrates the equipment used for the shrinkage test and a specimen being measured for shrinkage, respectively. The measurement was conducted according to the schedule in Table 5. The formula used to measure the shrinkage of the specimens is shown in Equation 1. Loss of moisture is calculated by using loss of mass, and the formula given is shown in Equation 2.

Concrete specimens in the mould. Concrete specimens in the curing water.

Figure 2. Concrete specimens in the mould and in the curing water.

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Shrinkage equipment.


Shrinkage test.

Figure 3. Shrinkage equipment and shrinkage test.

$$Shrinkage = \frac{L_D - L_O}{L_O} \qquad Equation\ 1$$

where

$L_D = Length\ on\ any\ day$

$L_O =$ Length on day 1

$$Moisture\ loss = \left(\frac{M_D - M_O}{M_O}\right) x100 \qquad \text{Equation 2}$$

where

$M_D = Mass\ on\ any\ day$

$M_O = Mass\ on\ day\ 1$

3. Results and Discussion

To address the objectives of the study, four figures are presented as follows.

- Figure 4: Drying shrinkage (microstrain) versus concrete age (days).
- Figure 5: Moisture loss (grams) versus concrete age (days).
- Figure 6: Moisture loss (%) versus concrete age (days).
- Figure 7: Trend lines of drying shrinkage versus moisture loss (%)

The positive value in Figure 4 indicates concrete shortening, while the negative value shows expansion (swelling). The positive value in Figures 5 and 6 demonstrates moisture loss where concrete becomes lighter and vice versa. Measurement was started on day 1 and taken as the base value.

Findings from Figure 4 show that all mix designs experienced expansion on day 2 except for the concrete containing 20% FRCA. The expansion of the control mix and concrete containing 30% FRCA is about the same, 40 microstrain and 37 microstrain, respectively. Meanwhile, concrete contains 10% FRCA, expanded very little, with a value of about 5 microstrains. Conversely, concrete containing 20% FRCA shrank as much as 16 microstrains. Many line intersections occur between days 2 and 7, which shows that chemical reactions are happening rapidly but at different rates for the hardening process. As a result, the concrete swells because of heat released during the hydration and shrinks due to cooling and evaporation (Glišić & Simon, 2000). After 7 days, the lines are quite stable, whereby the control mix and concrete containing 20% and 30% FRCA fluctuate in about the same pattern until day 21. In comparison, concrete containing 10% FRCA rises in a straighter line. Finally, at the age of 28 days, the shrinkage values for concrete containing 0%, 10%, 20% and 30% of FRCA are 76, 73, 124 and 51 microstrains, respectively.

Figure 5 indicates that the expansion of concrete containing 0, 10 and 30% FRCA on day 2 (from Figure 4) is due to moisture gain as much as 22, 35 and 45 grams, respectively. Although concrete with 20% FRCA shrank as much as 16 microstrains, it in fact acquired 28 grams of moisture. In general, the trend of moisture (mass) loss shown in Figure 4 is very similar for all concrete mixes except on day 21, whereby the control mix and concrete with 20% FRCA lost more mass than the other two concretes.

The mass loss of concrete containing 0%, 10%, 20% and 30% of FRCA at 28 days is 120, 110, 125 and 122 grams, which corresponds to shrinkage of 76, 73, 124 and 51 microstrains, respectively. Concerning these values, the drying shrinkage per gram of mass loss at 28 days is calculated and shown in Table 7. It is found that the values of shrinkage per mass are in the range of 0.42 to 1 microstrain per gram, which is smaller than the value given in a study by Klausen & Kanstad (2021). Klausen & Kanstad (2021) also suggested that the potential drying shrinkage caused by 9.5 g water loss is approximately 11 microstrains or 1.16 microstrains per gram.

Figure 6 presents the percentage of moisture loss against concrete age. The highest moisture loss was experienced by the concrete containing 20% FRCA throughout day 3 to the end of the test duration. In the same duration, the lowest moisture loss was gained by the concrete which contains 30% FRCA. At the age of 28 days, the percentage of water loss in ranking is 5.66% (20% FRCA), 5.27% (10% FRCA), 5.21% (0% FRCA) and 4.15% (30% FRCA).

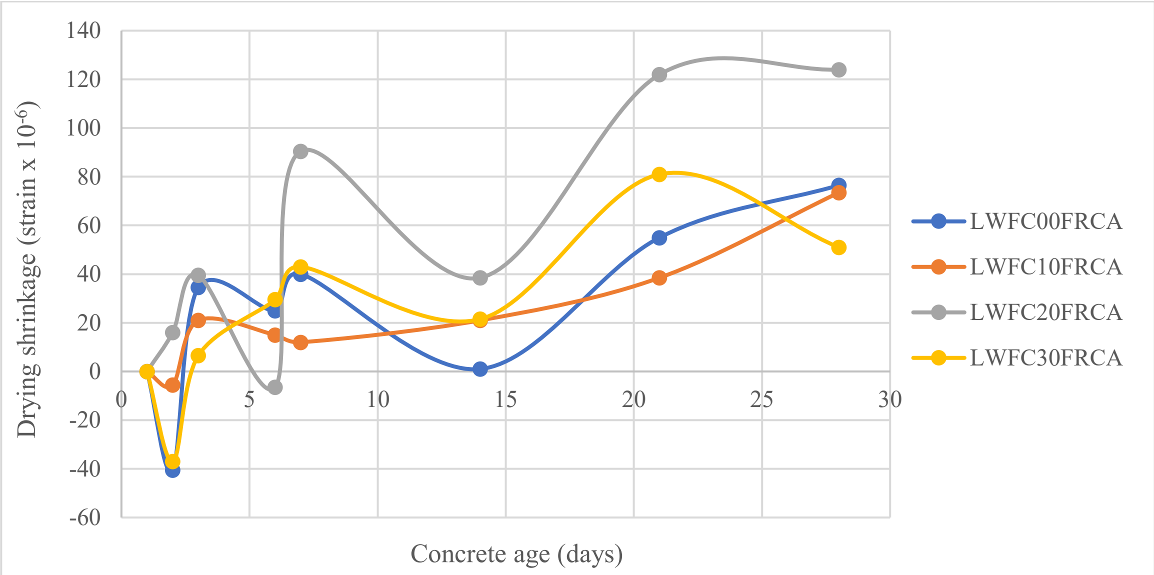

Figure 4. Drying shrinkage (microstrain) of LWFC versus concrete age (days).

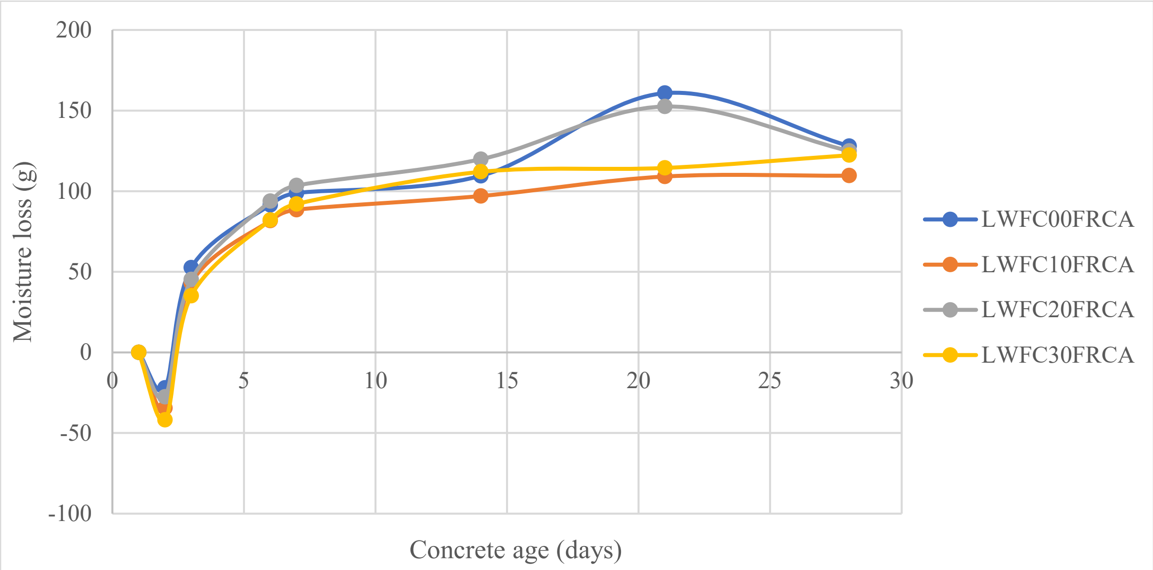

Figure 5. Moisture loss (g) of LWFC versus concrete age (days).

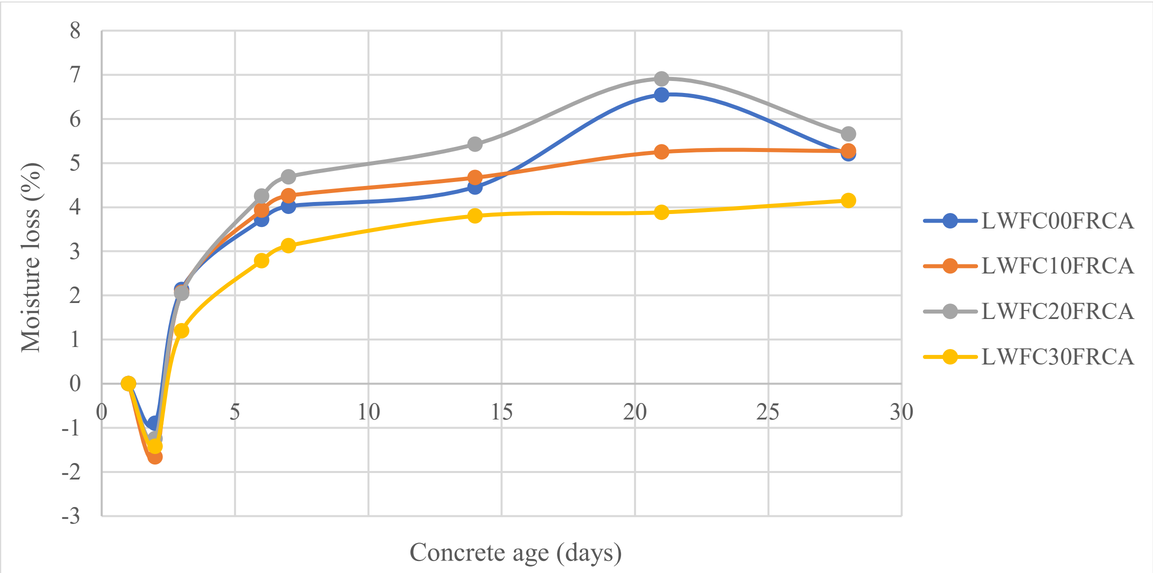

Figure 6. Moisture loss (%) of LWFC versus concrete age (days).

Table 7. Drying shrinkage (microstrain), moisture loss (g) and drying shrinkage per gram of moisture loss at 28 days of concrete age.

Design mix	LWFC00	LWFC10	LWFC20	LWFC30
Shrinkage (microstrain)	76	73	124	51
Moisture loss (gram)	128	110	125	122
Shrinkage per mass(microstrain / gram) at 28 days	0.60	0.66	0.99	0.42

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To investigate the relationship between drying shrinkage and loss of moisture content, Figure 7 is plotted. The trend lines and equations were created and shown in Table 8. All the R^2 values are positive, which shows a positive relationship between drying shrinkage and moisture loss for all the concrete mixes. The higher the moisture loss, the higher the drying shrinkage. Concrete containing 30% of FRCA scores the highest R^2, followed by concrete mixed with 0%, 10% and 20% of FRCA. Although LWFC20FRCA has the smallest score, the value of R^2 is very close to 0.5.

FRCA is highly porous and may therefore absorb more water than natural aggregate (Théréné et al., 2020). Hence, to achieve an ideal concrete mix, a large amount of FRCA must be provided with a higher quantity of water. In a condition where concrete is provided with more water than required, shrinkage increases. In this study, the smallest shrinkage at the age of 28 days is demonstrated by the concrete mix with 30% FRCA. This condition is proven by the highest R^2 value between shrinkage deformation and the percentage loss of moisture. Therefore, it is suggested that this concrete mix is considered the ideal mix in the scope of this study.

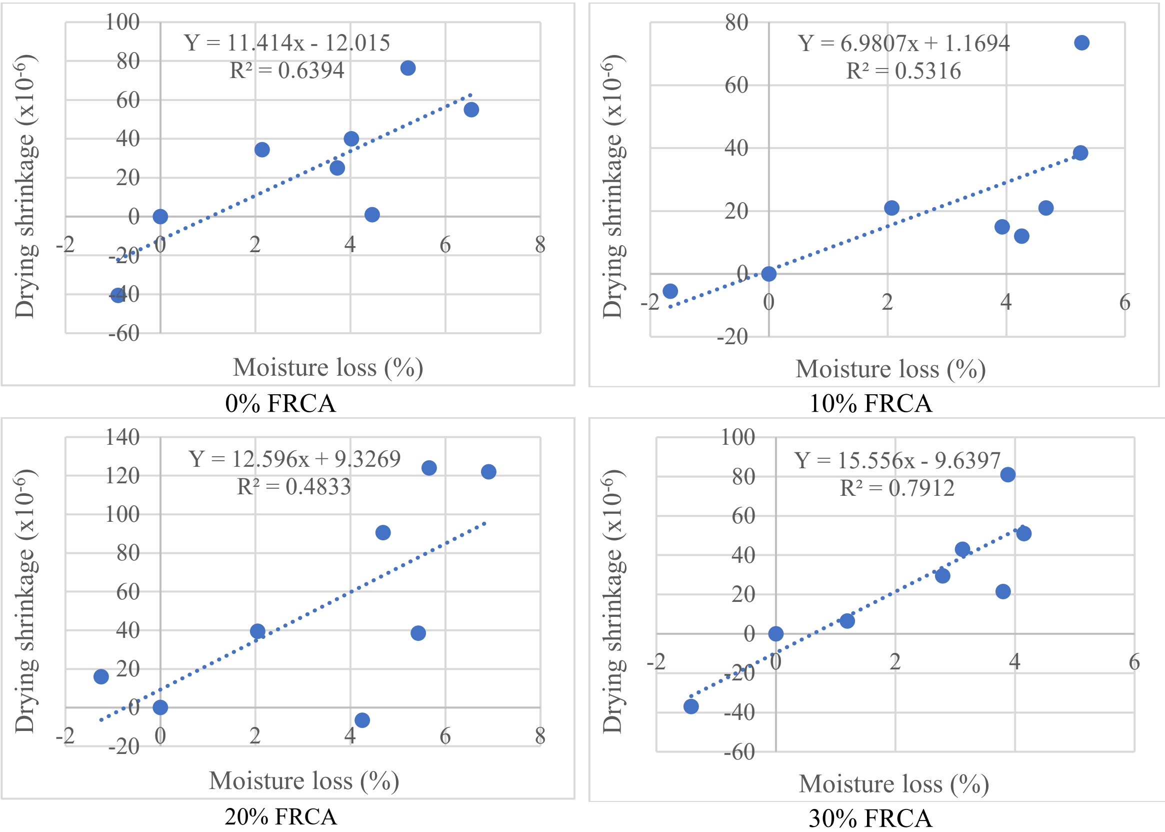

Figure 7. Trend lines of drying shrinkage versus moisture loss.

Table 8. Equations and correlations between drying shrinkage and moisture loss.

Mix Design	Equation	R^2 value
LWCA00FRCA	Y = 11.414x – 12.015	0.6394
LWCA10FRCA	Y = 6.9807x + 1.1694	0.5316
LWCA20FRCA	Y = 12.596x + 9.637	0.4833
LWCA30FRCA	Y = 15.556x – 9.6397	0.7912

4. Practical Implications

This study supports the sustainable use of recycled fine aggregates in lightweight concrete by identifying their effects on shrinkage performance. When an appropriate mix design is employed, such as incorporating shrinkage-reducing admixtures or pre-saturating the FRCA, the use of this material contributes to advancing circular construction practices. Understanding how FRCA influences drying shrinkage and moisture loss enables engineers to adjust key mix parameters, including water content, binder type, and FRCA percentage, to achieve a balance between workability and strength. Additionally, preventive measures can be implemented, such as optimizing curing conditions through controlled humidity, refining reinforcement detailing to reduce cracking, and limiting the use of high FRCA content in elements that are particularly sensitive to deformation, such as slabs and walls.

5. Conclusion

The results of this investigation are listed as follows. Every lightweight foam concrete utilized in this study shrinks in a fluctuating trend as it is subjected to a natural laboratory environment. The highest and lowest shrinkage value at 28 days comes from the concrete mixed with 20% and 30% of FRCA, respectively. The higher drying shrinkage observed in the concrete containing 20% fine recycled concrete aggregate (FRCA), compared to the 30% FRCA mix, may be largely influenced by the complex interplay between water absorption and desorption by the FRCA, cement hydration, and water evaporation (Zhang, 2022). To mitigate this effect, a higher water content may be required.

The difference in shrinkage deformation between these two concrete mix designs is 73 microstrains, whereby the biggest value is 2.4 times the smallest value. The trend of moisture loss is very similar for all concrete mixes. The biggest moisture loss at 28 days was experienced by the concrete having 20% FRCA, supporting the reason for the highest shrinkage strain. It must be noted that the porosity of the FRCA may change the overall water-cement ratio. The concrete may end up containing more water than required, whereby the excess water evaporates into the air and causes shrinkage due to drying. Therefore, it is crucial to modify the water content to obtain the optimum mix based on the amount of FRCA used. On the other hand, the smallest shrinkage strain and the best relationship between drying shrinkage and moisture loss are demonstrated by concrete which contains 30% of FRCA. Hence, this concrete mix design is considered the best with reference to the scope of this study.

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Declaration of Conflicting Interests

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

Author Contribution

Conceptualisation, Dr. Mohd Afiq Mohd Fauzi; Methodology, Dr. Mohd Afiq Mohd Fauzi; Validation, Norisham Ibrahim; Analysis, Izzah Inshirah Rasli; Investigation, Izzah Inshirah Rasli; Resources, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam; Data Curation, Norisham Ibrahim; Writing-Draft Preparation, Izzah Inshirah Rasli; Writing-Review & Editing, Norisham Ibrahim; Visualisation, Zubaidah

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All authors have reviewed and approved the final version of the manuscript for publication

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