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**Research Article**

# Use of pumice aggregate in cementitious rheoplastic lightweight concrete

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## ABSTRACT

Rheoplastic lightweight concrete (RLC) is generally designed for pumping applications as fluid concrete free from segregation. Concrete is produced using polymeric admixtures to enhance concrete workability, strength, drying shrinkage, and durability. This research investigated the suitability of natural porous pumice aggregates in Turkey to obtain rheoplastic lightweight concrete with cement content in normal ranges. To produce and experience rheoplastic concrete mix design data, rheoplastic lightweight concrete mixes were tested with fine pumice aggregate (FPA) and coarse pumice aggregate (CPA) supplied from the Nevşehir region of Turkey. For rheoplastic lightweight concrete with cement contents in the 250 to 400 kg/m$^3$ range, the percentage of fine pumice aggregates required was in the 73.6-81.0% range with complimentary water/cement ratios of between 0.53 and 0.68. The upper compressive strength limit was circa 30 N/mm$^2$. The research findings determined that the rheoplastic concrete samples with pumice aggregate met the design requirement of a slump value of 200 mm for fresh concrete predicted for fluid concrete forms. While technical properties of hardened concrete such as oven-dry density (1198-1362 kg/m$^3$), strength values, static elasticity modulus (9236-10756 MPa), thermal expansion coefficient (5.354 x10$^{-6}$/°C - 6.929x10$^{-6}$/°C) and thermal conductivity value (0.405-0.619 W/mK) decrease with increasing aggregate/cement ratios, they increase with increasing cement dosage. In addition, the high amount of fine pumice in concrete composition results in lower drying shrinkage and wetting expansion with decreasing cement dosage. The technical findings showed that RLC might be produced by using a superplasticizer and air-entraining admixtures and mixtures of different sizes of pumice aggregates.

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## 1. INTRODUCTION

Rheoplastic concrete is a concrete mixture that exhibits high strength, containing selected cement and aggregate, set accelerator, and high plasticizer additives in the correct dosage. It is a concrete form with high workability and a meager water-cement ratio, generally free of segregation and bleeding. The use of different types of artificial and/or semi-artificial lightweight aggregates in this type of concrete production and their compatibility with the application area is a research subject requiring detailed

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investigation. Lightweight aggregate concrete (LWAC) is a widely used construction material that offers technical and economic advantages in the construction industry [1-3]. Unit volume weight values of lightweight aggregate concrete generally vary between 800-1800 kg/m$^3$ [4], and their compressive strength after setting varies between 30-80 N/mm$^2$ [1]. LWAC has been used in building projects for load-bearing and/or semi-load-bearing purposes from past to present. However, porous, lightweight aggregates of different origins are also being used to produce (RLC) rheoplastic lightweight concrete, as seen in the literature [2, 3, 5-8].

Lightweight aggregated concrete using pumice (PALWC) could be used in various applications in the construction industry due to its advantages, such as low unit weight, high contribution to heat insulation, and sound insulation. Mixing and placing concrete containing lightweight aggregates is much more complex than conventional concrete practices. Due to their porosity and low specific gravity, lightweight aggregates tend to float with a decreased cohesion value, especially in concrete mixtures with fluid properties [2-9].

RLC is a fluid concrete with a slump of at least 200 mm and can flow easily but does not form segregation. It contains a plasticizer, synthetic fiber if needed, and special additives in its composition. It is a fluid concrete with the same water/cement ratio as additive non-slump concrete (25 mm) [6, 10]. This type of concrete mix is generally designed for pumping applications. Some researchers (including [5, 8, 9, 11, 12]) studied the innovations and use of polymer-modified concrete. Beyond that, there is limited research on using polymers in RLC. Using high range water reducing and air-entraining admixtures in PALWC, rheoplastic mixes (i.e., fluid mixtures that do not segregate but have a low water/cement ratio) can be obtained. This concrete mix approach creates pumice aggregated rheoplastic lightweight concrete, symbolized as "PARLC." It is also possible to obtain PARLC at lower specific gravity without signs of segregation with high range water reducing and air-entraining additives. In addition to overcoming the disadvantages of segregation, PARLC has all the advantages of a meager water/cement ratio. Mainly, RLC can produce materials with better and more continuous thermal insulation; due to its low permeability, the thermal insulation properties are less affected by the humidity conditions of the environment [3, 4].

Several commercially available admixtures, which meet the requirements of ASTM C260 [13] and ASTM C494 [14], have been incorporated in experimental mixes during lightweight structural concrete investigations. All mixes incorporating superplasticizers successively produced high-strength concrete with wet consistencies [7, 15]. In this study, experimental research findings test the provision of PARLC properties and applicability in laboratory conditions by using high water-reducing, air-entraining, and thickening polymeric additives of pumice aggregates with a naturally porous structure are discussed.

## 2. EXPERIMENTAL STUDY

### 2.1. Purpose of Assessment

The assessment of this study includes a series of analysis findings to investigate the suitability of pumice aggregates obtained from the Nevşehir region to produce PARLC in coarse and fine-size fractions and to determine suitable mixture design data for this concrete type. In technical evaluation, cement as a primary binder, pumice coarse and fine aggregates with various additives and pump aids would be used. When it is necessary to improve the pumpability and flowability of concrete, using very fine-grained natural sand or an inorganic filler material could be considered a last resort.

### 2.2. Materials

Ordinary Portland cement (PC) (ASTM Type I, 42.5 N/mm$^2$) was used to prepare concrete test samples. Blaine's number of cement was 3245 cm2/g, and initial and final setting properties were 250 min and 306 min according to ASTM C191 [16] standard. The specific gravity of Portland cement was 3.1 g/cm$^3$. The chemical analysis of PC is given in Table 1.

Pumice is widely used as lightweight concrete aggregate in sectoral and industrial applications. It is highly resistant to other chemical materials except for HF acid interaction. It generally exhibits chemically inert material characteristics. As a lightweight aggregate, pumice aggregate (PA) of volcanic origin was obtained from a quarry in Nevşehir, Turkey (Figure 1). Pumice aggregate samples were brought to the laboratory with their natural moisture as they were taken from the quarry and firstly dried in an oven. Afterward, it was subjected to a crushing process and classified as coarse and fine aggregates in two different sizes. The coarse pumice aggregate size range is 4-12 mm, and the fine pumice aggregate is 0-4 mm. Some physical and mechanical properties, such as water absorption, dry bulk density,

**Table 1.** Chemical composition of the materials

| Major element | PC (%) | PA (%) |
|---|---|---|
| $SiO_2$ | 20.61 | 74.10 |
| $Al_2O_3$ | 5.64 | 13.45 |
| $Fe_2O_3$ | 4.10 | 1.40 |
| CaO | 61.90 | 1.17 |
| $Na_2O$ | 0.11 | 3.70 |
| $K_2O$ | 0.86 | 4.10 |
| MgO | 2.64 | 0.35 |
| LOI | 1.35 | 1.66 |

**Figure 1**. Symbolic view of pumice aggregate before processing.

elastic modulus, and compressive strength, are determined according to TS EN 1097-6 [17], TS EN 1097-3 [18], TS 699 [19], and determined as 23±4%, 870±55 kg/m³, 10.1±1.2 GPa, and 24.2±1.5 N/mm², respectively. The chemical properties of cement and pumice aggregate used are given in Table 1.

0-2 mm calcite powder was also used as an inorganic filling material to prepare PARLC samples. Calcite powder was procured from the Aksaray region as ready-sized material under normal market conditions. Its average bulk density and specific gravity were 1290 kg/m³ and 2.72, respectively.

Sieve analysis of pumice aggregate and calcite filling materials is represented in Figure 2.

A high-range water-reducing admixture commercially available in civil engineering applications could be used in liquid form. A polymeric additive designed as a special additive for rheoplastic concrete was used in the mixtures supplied from market conditions to provide concrete consistency and fluidity. This admixture is in liquid form and

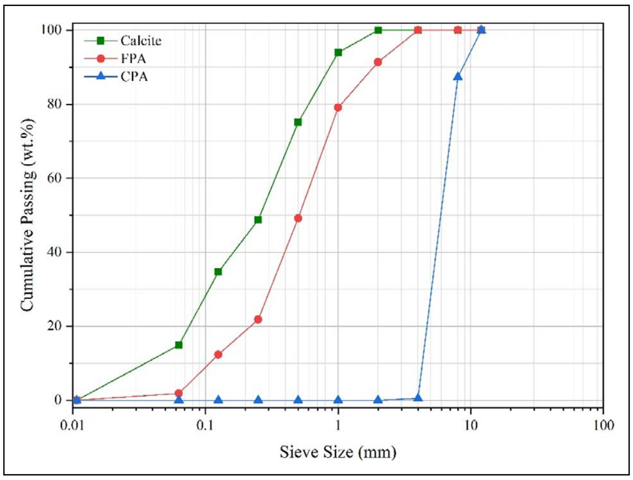


**Figure 2**. Sieve analysis of calcite, FPA, and CPA.

is a high-performance superplasticizer for slump retention and high-strength concrete. It is a chloride-free super plasticizing admixture specially designed to produce high-quality rheoplastic concrete. It disperses by electrokinetic action in the concrete mixture, enabling the water phase of the concrete to perform more effectively. This rheoplastic admixture could be used as a dosage of 1.50-2.50 liters/100 kg cementitious material to reach the high concrete strengths. The additive used meets the requirements prescribed for additives in ASTM C 494 [14] for Type A and B. Furthermore, it improves the pumpability of the mixture [10, 20, 21].

An air-entraining admixture, commercially available in civil engineering applications, was also used in liquid form. This admixture also meets the requirements prescribed in ASTM C260 [13] standard. It does not contain air additives, reinforcement embedded in concrete, or any chemical component that will corrode prestressed steels. This additive does not contain any calcium chloride or other chloride-based ingredients [22]. Tap water was used as mixing water.

### 2.3. Mix Design

More than one mixture was designed for the analysis of PARLC samples. Mixing ratios and concrete density values are given in Table 2. Each mixture series prepared in the study was coded M1 to M6 according to the varying mix-

**Table 2.** Mixing ratios and concrete density values

| Mix | A/C | Cement (kg/m³) | FPA (kg/m³) | CPA (kg/m³) | Filler (kg/m³) | Fines (%) | W/C | Fresh density (kg/m³) | Air dry density (kg/m³) |
|---|---|---|---|---|---|---|---|---|---|
| M1 | 2.22:1 | 400 | 556 | 199 | 133 | 73.6 | 0.55 | 1580±28 | 1362±19 |
| M2 | 2.42:1 | 375 | 571 | 201 | 136 | 74.0 | 0.61 | 1590±22 | 1358±34 |
| M3 | 2.63:1 | 350 | 584 | 199 | 138 | 74.6 | 0.65 | 1585±19 | 1347±15 |
| M4 | 2.83:1 | 325 | 589 | 192 | 138 | 75.4 | 0.68 | 1564±33 | 1322±8 |
| M5 | 3.07:1 | 300 | 600 | 182 | 138 | 76.7 | 0.70 | 1541±17 | 1297±27 |
| M6 | 3.51:1 | 250 | 604 | 142 | 132 | 81.0 | 0.72 | 1416±21 | 1198±21 |

ing ratios. Different aggregate/cement ratios (A/C) of 2.22, 2.42, 2.63, 2.83, 3.07, and 3.51 were used for the concrete mixtures, respectively. Highly water-reducing admixture (aqueous solution of modified polycarboxylates) was used as a constant dosage of 1.8 liters/100 kg of cementitious material, and an air-entraining agent (aqueous solution of organic materials) was also used in a constant dosage of 100 ml/100 kg cement for all the mixtures. These addition rates were determined through trial batch testing for which the target slumps were 150+ mm. For rheoplastic lightweight concrete with pumice aggregate in the 250 to 400 kg/m$^3$ range of cement contents, the fineness ratio in the total amount of pumice aggregate required was in the 73.6-81.0% range with free water/cement ratio between 0.55 to 0.72 (where the free water does not include water absorbed by the aggregates (ESCSI, 2005). The upper compressive strength limit was circa 30 N/mm$^2$. Eguchi et al [23], Teo et al [24], Moreover, Evangelista and Brito [25] reported similar concrete mixture proportions using different lightweight aggregates for lightweight structural concrete.

All pumice aggregates were pre-wetted to account for their porous nature. In order to achieve maximum rheoplasticity for PARLC samples, the aggregate must be pre-wetted before mixing since the surfaces of the pumice aggregates are dry, and the surface tension values are high. During the pumping process, pre-wetting is done to minimize or completely prevent water absorption into the pores of the aggregate. In this way, the pumpability performance of concrete would also increase. This application also enabled lower water/cement ratios for the mixtures. This process also helps to minimize the slump of concrete [6]. In the experimental program, materials in the mixture were mixed in the following order: First, half of the water, cement, and pumice fine aggregate was mixed for about 3 minutes. Second, the remaining water and water-reducing mixture were added to the mixer and mixed for about two more minutes. The third air-entraining agent was added to the mixture and mixed for about 2 minutes. Finally, pre-wetted coarse pumice aggregate was added, and mixing continued for about 6 minutes until a homogeneous concrete consistency was obtained.

### 2.4. Methods

All concrete test samples were cast 150x150x150 mm in steel molds and compacted by mechanical vibration. For each mixture, six samples were prepared and demolded approximately 24 h after casting. The samples were cured in water at 20 °C for 3, 7, 28, and 90 days until the day before testing. For water absorption tests, 150 x 300 mm cylindrical samples were prepared. The samples were cured in water for 28 days. These samples were then dried in a 105 °C fan oven for 24 hours before testing and immersed at 22 °C in a water bath with a thermostat for 30 to 72 hours. The samples were taken from the water after 72 hours, and the saturated surface was weighed in dry condition. For the flexural strength test, six pieces of 100x100x350 mm prismatic samples for each mixture were produced according to TS EN 12390-5 [26], and they cured the same as compressive strength samples. The flexural strength test was carried out under loading speed conditions of 0.05 MPa/s.

## 3. EXPERIMENTAL RESULTS

### 3.1. Fresh Concrete Properties

The properties of PARLC test samples prepared at different mixing ratios are presented in Table 3. The initial slump was 200±8 mm for all fresh concrete mixes according to TS EN 12350-2 standard [27]. The workability of fresh concrete was maintained as self-leveling without any signs of water bleeding or aggregate segregation. The appearance of the fresh concrete was excellent and sticky for all mixes.

### 3.2. Hardened Concrete Density

Density values of PARLC test samples after 28 days of curing were measured for their air-dry condition, and the values varied in the range of 1198 and 1362 kg/m$^3$ based on cement contents and aggregate/cement ratios. These values are all in the commonly accepted range of lightweight concrete density between 800 – 1800 kg/m$^3$. As cement dosage increases, the hardened concrete's density also increases. Aggregate/cement ratios also affect concrete density. The observation for this effect was that increasing the aggregate/cement ratio reduces concrete density. The relationship between 28-day density values of the concrete test samples depending on cement dosage is given in Figure 3 according to the different A/C ratios.

**Table 3.** Some properties of PARLC samples

| Properties | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|
| A/C ratio | (2.22: 1) | (2.42: 1) | (2.63: 1) | (2.83: 1) | (3.07: 1) | (3.51: 1) |
| Cement content (kg/m$^3$) | 400 | 375 | 350 | 325 | 300 | 250 |
| Fines content (%) | 73.6 | 74.0 | 74.6 | 75.4 | 76.7 | 81.0 |
| Thermal expansion coefficient (saturated) /°C | $6.929x10^{-6}$ | $6.873x10^{-6}$ | $6.681x10^{-6}$ | $6.377x10^{-6}$ | $6.051x10^{-6}$ | $5.354x10^{-6}$ |
| Slump (mm) | 192 | 200 | 202 | 203 | 205 | 208 |
| Drying shrinkage (%) | 0.038 | 0.032 | 0.030 | 0.028 | 0.026 | 0.026 |
| Total moisture movement (%) | 0.069 | 0.056 | 0.053 | 0.05 | 0.047 | 0.049 |
| Thermal conductivity (W/mK) | 0.619 | 0.568 | 0.548 | 0.524 | 0.503 | 0.405 |

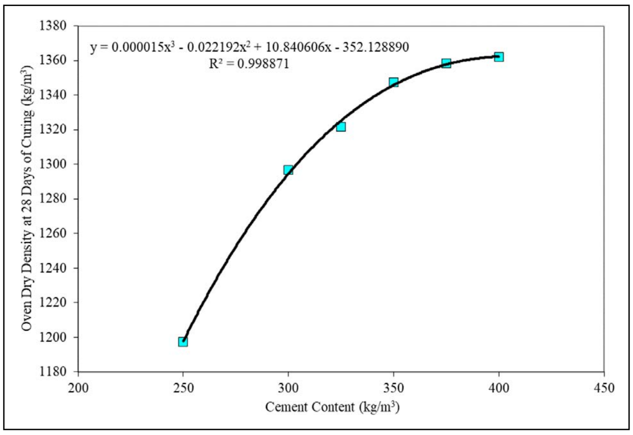


**Figure 3**. Cement amount versus density of concrete.

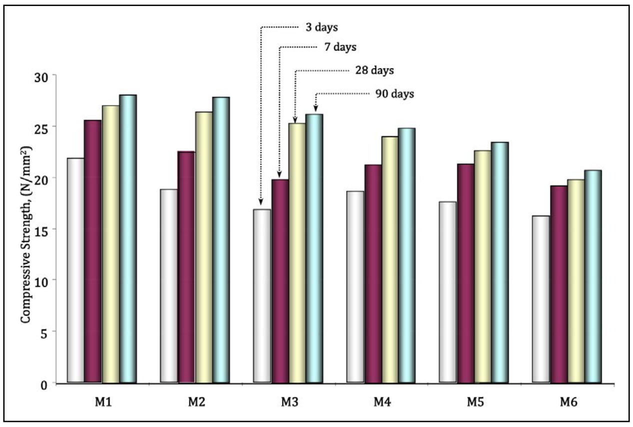


**Figure 4**. Curing time versus compressive strength of concrete.

### 3.3. Strength and Elasticity

The strength development of PARLC samples, depending on the curing time, is given in Figure 4. In order to eliminate potential strength changes due to surface moisture, concrete samples were brought to the saturated surface dry condition before testing. It is observed that there is an improvement in the strength values of all concrete samples in each period when considering the curing times. However, as strength-gaining features of PARLC samples were examined, it was observed that the strength improved with a much lower increase in strength until the 60th day period after casting. Predictably, this small amount of strength increases after the 60th day and could be accepted as a constant value for PARLC samples. This improvement showed an even more significant value when the fine grain ratio in the concrete mixture was decreased. Especially over a long period, concrete samples reach a strength value that can be considered constant.

Enhancement in compressive strength is occurring as expected. The strength development due to the change in the A/C ratio of concrete samples in an equivalent curing time (28 days of curing) is also given in Figure 5. Strength values at 28 days and three months are given in Table 4. Air dry densities of PARLC test samples with 250 and 300 kg/m³ cement content were recorded as 1198 and 1297 kg/m³, respectively.

The elastic modulus for PARLC lowers with a decrease in cement content (higher A/C ratios). The static modulus of elasticity varied from 9236 to 10756 N/mm² at 28 days, as shown in Table 4. Generally, the elastic modulus of low-density concrete with lightweight aggregates is lower than conventional concrete because lightweight aggregates undergo greater deformation (more than 50%) than higher-density aggregates [28]. Han and Kim [29] determined the static elasticity modulus of concrete between 25 GPa and 29 GPa at 28 days of curing. The findings obtained in this experimental study showed that the static modulus of elasticity of PARLC mixtures was approximately 37-44% of the static modulus of elasticity for average weight concretes. According to American Concrete Institute (ACI) [30], the compressive strength range of lightweight concrete is 2-14 MPa with 1000-1400 kg/m³ density. Similarly, in this experimental study, PARLC densities change between 1198 and 1362 kg/m³, and the compressive strength of the concrete samples varies between 19.8 to 27 MPa providing ACI moderate strength limitations.

### 3.4. Flexural Strength

Flexural strength values of concrete samples on the 28th and 90th days are given in Table 4. Their values varied from 4.58 to 5.68 N/mm² at 28 days and from 4.74 to 6.06 N/mm² at three months, depending on the different

**Table 4.** Some mechanical properties of PARLC samples.

| Mix | Compressive strength (N/mm²) | | Static elasticity modulus (N/mm²) | Flexural strength (N/mm²) | |
|---|---|---|---|---|---|
| | 28 days | 90 days | 28 days | 28 days | 90 days |
| M1 | 27.0 | 28.0 | 10756 | 5.68 | 6.06 |
| M2 | 26.4 | 27.8 | 10627 | 5.50 | 5.84 |
| M3 | 25.3 | 26.2 | 10395 | 5.32 | 5.62 |
| M4 | 24.0 | 24.8 | 10119 | 5.14 | 5.40 |
| M5 | 22.6 | 23.4 | 9816 | 4.96 | 5.18 |
| M6 | 19.8 | 20.6 | 9236 | 4.58 | 4.74 |

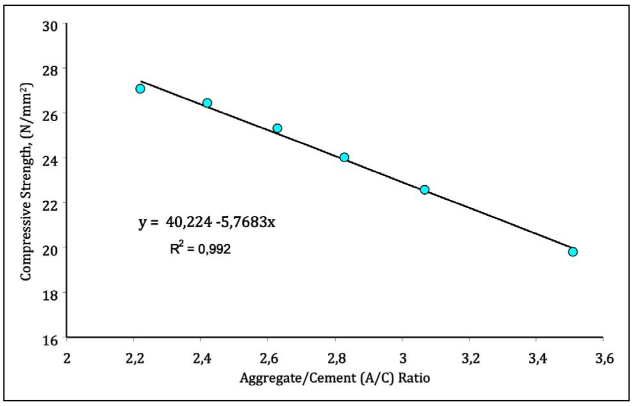


**Figure 5**. Aggregate/cement ratio versus compressive strength.

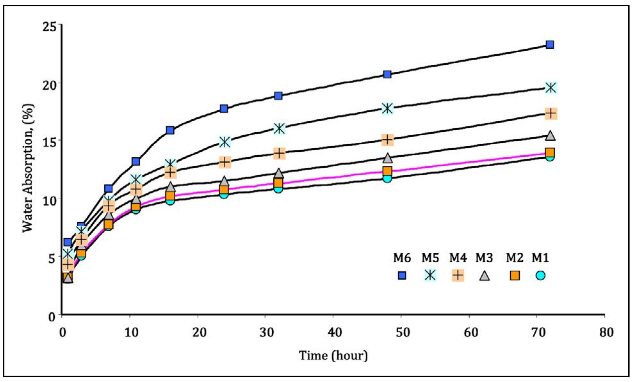


**Figure 6**. Water absorption versus time for PARLC samples.

A/C ratios of the mixture. PARLC has a lower flexural strength for a specific compressive resistance than conventional normal-weight concrete. Although lightweight concrete has more excellent cement mortar resistance and mortar-aggregate adherence levels than an equal resistance regular weight concrete, the aggregate's low tensile stress resistance noticeably lowers the lightweight conglomerate's tensile stress resistance [28]. Similar results were achieved in this experimental research—flexural strength values of the concrete mixtures given in Table 4. The table shows how this difference varies as a function of the composition and compression resistance of different A/C ratios. This study showed an average difference of 24% after 28 days of curing and 28% after 90 days between the flexural strength of the concrete with the lowest cement dosage and the concrete with the highest cement dosage. The practical reason for this is the change in fine material ratio and the weakening of the cohesion value of the matrix structure.

### 3.5. Water Absorption of Hardened Concrete

Water absorption values of PARLC samples were measured between 30 minutes and 72 hours in 9 different periods through a series of measurements. As with average weight concretes, water absorption values were higher for lower cement dosage mixtures (higher A/C ratios). The values were between 3.5% and 7% after 30 minutes of immersion according to different A/C ratios, whereas in the range between 13% and 22% after 72 hours of immersion. As expected, the water absorption of PARLC samples was rapid for up to 24 hours; after that, the samples absorbed low water. This effect was based on the toughness of the cement paste surrounding the porous aggregate in the matrix structure and the pressure height above the concrete. The increase in cement content provides a good quality cement paste; therefore, water absorption of the concrete is lower. Another main factor affecting the water absorption was the A/C ratios. Lower A/C ratios have given less water absorption. This relationship was presented in Figure 6 for different PARLC mixtures.

A rapid change in water absorption property for all six mixtures occurred circa 8 hours after immersion. On the other hand, moisture increase is different currently for PARLC mixtures, increasing with a decrease in cement content, as follows: 400-8.8%, 375-9.2%, 350-9.9%, 325-11.4%, 300-12.3%, and 250-15%, respectively.

### 3.6. Thermal Conductivity

The thermal conductivity of PARLC samples is given in Table 3 at 3% moisture condition. Coefficients of thermal conductivity varied from 0.405 to 0.619 W/mK based on the increase of A/C ratios. The test results concluded that the thermal insulation properties of PARLC samples depend on their mineralogical composition, residual moisture content, and apparent densities. Increased cement content (higher density) reduced the thermal insulation property of PARLC samples. However, it has been observed that the A/C ratio of the mixture is an important area of interest in the thermal conductivity of pumice aggregated concrete. An increase in porous pumice aggregates in the mixture (higher A/C ratio) decreased the thermal conductivity of concrete samples up to 32-37%. The interaction between densities of test samples conditioned to 3% humidity and thermal conductivity values are analyzed in Figure 7.

In order to determine the thermal conductivity values of PARLC samples, which can be considered partially humid, a series of tests were also performed in this research study. According to the resulting data, an empirical equation was tried to develop as an estimation approach for thermal conductivity values of PARLC with particular reference to Nevşehir pumice aggregate. In the formula created to determine the thermal conductivity coefficients of the samples with different moisture content, the thermal conductivity coefficients of the samples containing different moisture content were determined with the hot-box apparatus and compared with each other. The results showed that the conductivity in PARLC samples increases by 4.7% for each volume percent of moisture content. This relation was formulated for PARLC as given below:

$$\lambda_m = \lambda_0 \times (1 + 4.7 \times M) \quad (1)$$

where;

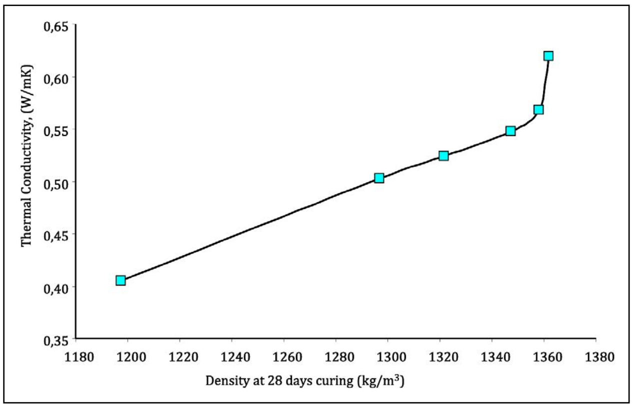


**Figure 7**. Density versus thermal conductivity of concrete.

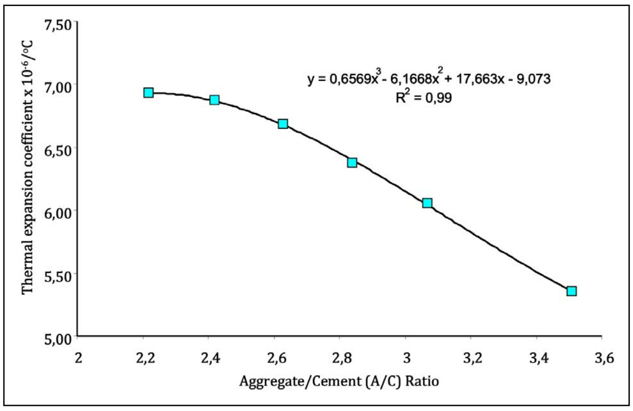


**Figure 8**. A/C versus thermal expansion coefficients of concrete.

$\lambda_m$: thermal conductivity coefficient at moisture condition, W/mK

$\lambda_0$: thermal conductivity coefficient at 3% moisture condition, W/mK

M: moisture content of the concrete, %.

### 3.7. Thermal Expansion

Thermal expansion coefficients of PARLC test samples after 28 days of setting varied between 5.354 x$10^{-6}$/°C and 6.929x$10^{-6}$/°C depending on A/C ratio change (Table 3). Thermal expansion coefficients of conventional concrete with average density vary between 12x$10^{-6}$/°C and 13x$10^{-6}$/°C [31]. Thermal expansion coefficients of test samples are 45-54% of the values of normal weight concrete, with the effect of porous pumice aggregates in the concrete samples and aggregate particle size distribution.

As a general trend, the thermal expansion property decreases when the mixture's A/C ratio (having low cement content) increases. An interaction is obtained between the A/C ratio in the mixture and thermal expansion in the saturated state, as shown in Figure 8. There is a good polynomial relationship between the thermal expansion property of PARLC and the A/C ratio. It was determined that while the thermal expansion amount was relatively low at low A/C ratio values, the amount of thermal expansion decreased rapidly due to an increase in the A/C ratio.

### 3.8. Moisture Movement

Moisture movement characteristic of lightweight aggregated concrete depends on the quantity and matrix structure of cement paste, environmental conditions such as the extent of exposure and humidity, as well as type of aggregate, etc. [32, 33]. Table 3 shows drying shrinkage and wetting expansion at 90 days. The results show drying shrinkage from 0.026% to 0.038%, whereas wetting expansion varied from 0.021% to 0.031%. It was observed that the drying shrinkage of standard-weight concrete is more significant than that of PARLC samples by 28-31%. Therefore, the mixture's cement content and fines ratio were experienced as primary interests in drying shrinkage in pumice aggregated concrete. They applied more fine pumice aggregates with reducing cement content rather than coarse ones, reducing concrete samples' shrinkage to 22-27%. Similar effects were also reported on the wetting expansion feature for PARLC mixtures. The augmentation of concrete density and cement content (lower A/C ratio) increased wetting expansion values for PARLC samples. Values of drying shrinkage for the M5 and M6 mixes were the same numerical magnitude. It may be more meaningful to examine the total amount of moisture movement to evaluate the shrinkage of concretes containing porous aggregates in more detail. In concrete samples, total moisture movement can be considered the total value of the drying shrinkage and wetting expansion amounts. Parallel to the drying shrinkage and wetting expansion findings, the total moisture movement amount for PARLC samples also shows a similar trend. As the A/C ratio increases, the total amount of moisture movement decreases, and the total amount of moisture movement is ranged between 0.049% and 0.069 based on A/C ratios. On the other hand, drying shrinkage and wetting expansions of PARLC samples appeared to follow a slightly linear trend.

## 4. CONCLUSIONS

The findings of this study are briefly summarized below:

1. Rheoplastic concrete with a moderate strength value can be produced using lightweight pumice aggregates ranging from 250 to 300 kg/$m^3$ for cement contents. Compressive strengths can be obtained between 20 and 23 N/$mm^2$ using these cement contents.
2. Rheoplastic lightweight concrete can be produced using pumice coarse and fine lightweight aggregate to meet the requirements of ACI classification subject to ceiling in the 25 – 30 N/$mm^2$ range for concretes for the normal range of cement amount of 350 to 400 kg/$m^3$.
3. For practical ready-mix supply and pump emplacement, the use of admixtures is predominantly a pumping aid supplemented by a normal water-reducing plasticizer and an air-entraining agent. The pumpability is not

considered sensitive to the generic type, but the correct choice of pumping aid is essential. From the trials undertaken, water-reducing admixture was found to give long workability times, cohesiveness, appearance, and early strengths for pumping.

4. It has been observed that rheoplastic concrete with pumice aggregate with superplasticizer and air-entraining additives in liquid form can produce mixtures with fluid properties with a slump of 210 mm without bleeding and separation.
5. As well as adding admixtures, the percentage of pumice fines is increased for pumpable mixes compared with similar mixes of lesser workability or emplacement requirements.
6. An increase in pumice aggregates in rheoplastic concrete reduces the thermal conductivity value of PARLC and makes the concrete matrix more insulated. The thermal conductivity value of concrete varies depending on the amount of aggregate in the concrete composition, porosity ratio, aggregate fineness ratio, and final concrete density. The thermal conductivity of PARLC was recorded as 2.1-3.5 times lower than normal-weight conventional concretes.

The mixtures' drying shrinkage is higher than those of wetting expansions. Drying shrinkage and wetting expansion values for the mixtures were found to be a function of concrete density and cement content. It was determined that the drying shrinkage and wetting expansion of rheoplastic concrete increased depending on the decrease in the pumice aggregate ratio and the increase in the cement dosage. It has been shown that the ratio of pumice aggregates in the porous structure of the concrete composition is a directly effective parameter on the total moisture movement of the matrix structure.

## ETHICS

There are no ethical issues with the publication of this manuscript.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## FINANCIAL DISCLOSURE

The authors declared that this study has received no financial support.

## PEER-REVIEW

Externally peer-reviewed.

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