# The Effect of Using Saturated Lightweight Aggregate on Shrinkage and Hydration Degree of High Performance Concrete

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## ABSTRACT

Deformations named as autogenous (chemical + autogenous) shrinkage related to parameters of cement dosage, water/cement ratio etc. in high performance concretes are studied. Prevention of autogenous shrinkage with outer water curing is not possible.

In this research, the effects of three different lightweight aggregate types used as internal water reservoir in high performance concrete were analyzed on shrinkage, hydration degree and strength properties in different curing media. The research findings show that -1/+2 mm saturated lightweight aggregates in concrete samples of 40% relative humidity medium reduce the autogenous shrinkage, improve the hydration degree and increase the compressive strength.

**Keywords:** Saturated lightweight aggregate, autogenous shrinkage, degree of hydration, compressive strength.

## 1. INTRODUCTION

Shrinkage may be defined as volume reduction in general. Hydraulic, chemical, autogenous and thermal shrinkage etc. occur at different rates for all composites based on cement, and these may be a reason for significant deformations in concrete structure.

Cement dosage and water/binding material ratio are quite different between traditional concretes (TC) and high performance concretes (HPC). Therefore, shrinkage (hydraulic, chemical, autogenous etc.) effects also vary in these concrete types.

Hydraulic shrinkage which is formed by reason of bleeding-evaporating is observed as dominant in TC. In addition to this case, effects of chemical and autogenous shrinkages are less than hydraulic shrinkage. Deformations related to chemical and autogenous shrinkages occurring in HPC without any change in weight may create a problem in terms of the strength and durability. The autogenous shrinkage can not be prevented by conventional curing techniques compared to TC due to the lower capillary pores moving through the pore water and the tightness of cement paste in HPC /1/. It is another debatable issue of chemical and autogenic shrinkages about which one includes the other in HPC. However, a few researchers explained that chemical shrinkage includes autogenous shrinkage. Because, during hydration process, gel phases forming in concrete or composite suck water from capillary pores. As a result, tensile stress forming within the pores causes shrinking /2/.

In this study, the effects of three different (saturated-dry surface) lightweight aggregate types (LWA) used as internal water reservoir in high performance concrete were analyzed in the shrinkage development. Similar studies were published in previous years /1, 3, 4, 5/. But, in this study, effects of water absorption, porosity, structure of the pores and grain size of LWA having different origin as internal water reservoirs are also examined. Furthermore, produced concrete samples were cured in the three different relative humidity (RH) conditions. The shrinkage, compressive strengths at 28 days and hydration degrees of concrete samples using LWA as additive materials were compared with control concrete samples (K). Mineral additive materials such as silica fume having high absorption capacity were not added in mortar mixings. So the shrinkage was not affected.

## 2. PHYSICAL PROPERTIES OF LIGHTWEIGHT AGGREGATES

In this study, two types of pumice aggregates having different physical and chemical compositions belonging to Isparta region (Karakaya pumice: KP, Gelincik pumice: GP) and amorphous silica (AS) aggregate from Keciborlu region were used as internal water reservoir. Each LWA group was categorized in two different grain sizes (+1/-2 mm; +2/-4 mm) with screening process. Grain densities and water absorption ratios of normal (quartz) and LWA were determined according to TS EN 1097-6 standard (Table 1) /6/.

**Table 1**

Apparent densities, saturated dry surface grain densities and rates of water absorption at 24 hours according to grain sizes of LWA and quartz sand

| Aggregate Groups | Apparent Density $\rho_a$ (g/cm$^3$) | Oven-Dried Grain Density $\rho_{rd}$ (g/cm$^3$) | Saturated – Dry Surface Grain Density $\rho_{ssd}$ (g/cm$^3$) | Water Absorption (at 24 h) $WA_{24}$ (%) |
|---|---|---|---|---|
| KP24 | 1,920 | 0,891 | 1,427 | 60,119 |
| KP12 | 2,237 | 1,000 | 1,553 | 55,257 |
| GP24 | 1,588 | 0,642 | 1,238 | 92,762 |
| GP12 | 1,813 | 0,732 | 1,328 | 81,472 |
| AS24 | 2,305 | 0,973 | 1,551 | 59,407 |
| AS12 | 2,227 | 0,988 | 1,545 | 56,307 |
| Quartz sand | 2,637 | 2,633 | 2,635 | 0,060 |

*KP: Karakaya Pumice GP: Gelıncik Pumice AS: Amorphous Silica 24: between 2-4 mm 12: between 1-2 mm*

Additionally, specific gravity of each LWA type was determined by pycnometer method. Real porosities, apparent porosities and closed pore rates of aggregate types were calculated using pycnometer test data and the results are given in Table 2 /7/.

**Table 2**

Dry unit weight, specific gravity, porosity and closed pore rate in each LWA type

| LWA Groups | Dry Unit Weight $\rho_{rd}$ (g/cm$^3$) | Specific Gravity $\rho_{ort}$ (g/cm$^3$) | Real Porosity $n_1$ (%) | Water Absorption by weight $M_{24}$ (%) | Apparent Porosity $n_0$ (%) | Closed Pore Rates (%) |
|---|---|---|---|---|---|---|
| KP24 | 0,891 | 2,58 | 65,45 | 60,119 | 53,59 | 11,87 |
| KP12 | 1,000 | | 61,22 | 55,257 | 55,28 | 5,94 |
| GP24 | 0,642 | 2,49 | 74,21 | 92,762 | 59,56 | 14,66 |
| GP12 | 0,732 | | 70,60 | 81,472 | 59,64 | 10,97 |
| AS24 | 0,973 | 2,39 | 59,30 | 59,407 | 57,79 | 1,50 |
| AS12 | 0,988 | | 58,66 | 56,307 | 55,64 | 3,02 |

The GP24 type of LWA has minimum unit weight value and maximum water absorption rate (by weight at 24 hour). The increase in unit weight values of LWA resulted in the reduction of water absorption rates. The closed pore rates of GP24, GP12 and KP24 are higher than the rates of other LWA groups. Nevertheless, apparent porosity values of the whole LWA groups are close to each other as seen in Table 1 /2/. According to the above mentioned information, the GP type of LWA is ideal for internal water reservoir. However, this case is related to releasing capability of water to concrete matrix from the LWA pores and to the homogeneity of grain within the concrete matrix. Microscopic images of each LWA type were also prepared and the structure, distribution and dimensions of pores were analyzed in order to clarify the above mentioned subjects.

The pores of KP are canal shaped and its pore size is greater than pore sizes of other LWA types, according to investigations of microscopic images of whole LWA types. The pore sizes of KP are greater than 10 μm and its pore lengths usually rise up to 100 μm (as seen in Fig.1). GP has homogenous pore distribution compared to KP and its pore sizes are usually less than 10 μm. The pore sizes of GP range from 10μm to 50 μm and distribution of these pores is not homogenous. The bigger pore sizes (>10μm) are connected with each other by the narrow channels. However, connection of the small pores was not recognized from microscope images (as seen in Fig.1).

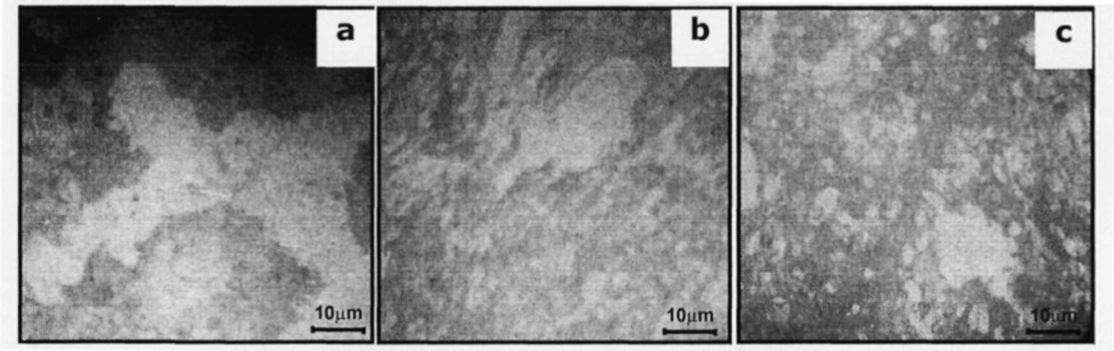

**Fig. 1:** Pore structures of KP (a), GP (b) and AS (c) aggregates (microscopic images)

When AS aggregate is compared with both of pumice aggregates (KP and GP), it is determined that it has a more homogenous structure than the others in terms of the distribution of pores. The pores of AS aggregate are usually circular forms and its sizes are smaller than 5μm. But, the pores larger than 10 μm were rarely observed (as seen in Fig.1).

## 3. EXPERIMENTAL STUDY

Primarily, thirteen different mortar mixtures were prepared to produce mortar bars and cube samples including two different grain sizes of KP, GP, AS types of LWA and not including LWA (K). These samples were cured in three different conditions. Portland cement (CEM I 42.5 R), granulated quartz sand (+2/-1 mm and -1/+0,063 mm) and superplasticizer were used in the preparation of mixture for the test. Cement properties are given in Table 3. The mixture designs of K and KP24 concrete samples are also given in Table 4.

Water to cement (w/c) ratio for the mixture design of K samples was chosen to be 0.25. The same w/c ratio was also used for the mixture designs of KP, GP and AS samples. Although the amounts of mixing water added to all of the mortar mixtures were constant, total water amount within unit volume of K, KP, GP and AS mortar mixtures varied. The real w/c ratio was calculated by the following equation. Total water amount added to the mixture ($w_t$) is "mixing water + water absorbed by the LWA". The saturated lightweight aggregate (sLWA) added mortar mixtures having two different $w_t/c$ ratios were prepared to determine the possible effects of $w_t/c$ ratios on the shrinkage and hydration degree. The sLWA rates (% $V_{LWA}$) are given in Table 5.

**Table 3**
Results of suitability analyses according to TS EN 197-1 standard of cement used in mortar mixtures [8]

| | Blaine[(1)] ($cm^2/g$) | Specific gravity ($g/cm^3$) | Initial Set (min.) | Expansion (mm) | Compressive Strength (MPa) | | | $SO_3$ (%) | L.O.I[(2)] (%) | Insoluble Residue (%) | $Cl^-$ (%) | $C_3S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | B2 | B7 | B28 | | | | | |
| **Avr.** | **3133** | **3,12** | **158** | **1** | **27,1** | **42,3** | **56,0** | **2,84** | **1,94** | **0,29** | **0,004** | **58,95** |
| **SDS.** | 123,84 | 0,01 | 22,04 | 0,0 | 2,14 | 2,21 | 1,38 | 0,13 | 1,14 | 0,091 | 0,003 | 4,17 |
| **Min.** | 2980 | 3,11 | 140 | 1 | 23,3 | 37,8 | 54,5 | 2,63 | 1 | 0,10 | 0,001 | 52,82 |
| **Max.** | 3370 | 3,14 | 200 | 1 | 30 | 44,6 | 58,1 | 3 | 3,83 | 0,4 | 0,01 | 64,57 |

*(1) Blaine : Cement fineness*
*(2) L.O.I : Lost on ignition*

**Table 4**
Mixture designs of the control (K) and LWA (KP24) added samples

| **Control (K) mixture design** | | | | | |
|---|---|---|---|---|---|
| **Ingredients** | $\rho_{real}$ ($g/cm^3$) | $\rho_a$ ($g/cm^3$) | $\rho_{ssd}$ ($g/cm^3$) | W (g) | V ($cm^3$) |
| Cement | 3.120 | - | - | 700 000 | 224.359 |
| Water | 1.000 | - | - | 175 000 | 175.000 |
| Silica Sand | - | 2 637 | - | 1516 767 | 575.186 |
| LWA | - | - | 1.545 | 0.000 | 0.000 |
| Super plasticizer | 1.100 | - | - | 28.000 | 25.455 |
| Air | - | - | - | - | 0 000 |
| Water absorption (%) of LWA | 0.000 | %$V_{LWA}$ | 0.000 | *2419.767* | *1000 000* |
| Addition mixing water[1] (g) | 0.000 | $w_t/c$ | 0.250 | Unit weight [2] | 2.420 |
| **6.5% KP 24 added mixture design (by volume)** | | | | | |
| Cement | 3 120 | - | - | 700 000 | 224.359 |
| Water | 1.000 | - | - | 175 000 | 175.000 |
| Silica Sand | - | 2.637 | - | 1344 909 | 510.015 |
| KP 24 | - | - | 1.427 | 93 000 | 65.172 |
| Super plasticizer | 1.100 | - | - | 28 000 | 25.455 |
| Air | - | - | - | - | 0 000 |
| Water absorption (%) of LWA | 0 601 | %$V_{LWA}$ | 6.517 | *2340.909* | *1000.000* |
| Addition mixing water[1] | 55.911 | $w_t/c$ | 0.330 | Unit weight [2] | 2.341 |
| **3.3% KP 24 added mixture design (by volume)** | | | | | |
| Cement | 3.120 | - | - | 700.000 | 224.359 |
| Water | 1.000 | - | - | 175.000 | 175.000 |
| Silica Sand | - | 2,637 | - | 1429.914 | 542.250 |
| KP 24 | - | - | 1.427 | 47.000 | 32.936 |
| Super plasticizer | 1.100 | - | - | 28.000 | 25.455 |
| Air | - | - | - | - | 0.000 |
| Water absorption (%) of LWA | 0 601 | %$V_{LWA}$ | 3.294 | *2379.,914* | *1000 000* |
| Addition mixing water[1] | 28.256 | $w_t/c$ [2] | 0.290 | Unit weight [3] | 2.380 |

*1. Water amount ( by weight) of LWA at saturated-dry surface condition*
*2. Total water amount of mortar mixture / cement ratio.*
*3. Theorical density of fresh concrete($kg/m^3$)*

**Table 5**

Addition rates (by volume) of saturated-dry surface LWA according to aggregate types and $w_t/c$ ratios

| | K | KP 24 | KP 12 | GP 24 | GP 12 | AS 24 | AS 12 | KP 24 | KP 12 | GP 24 | GP 12 | AS 24 | AS 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\%V_{LWA}$ | 0 | 6,50 | 6,50 | 4,84 | 5,20 | 6,06 | 6,48 | 3,30 | 3,25 | 2,42 | 2,60 | 3,03 | 3,24 |
| $w_t/c$ | 0,25 | 0,33 | 0,33 | 0,33 | 0,33 | 0,33 | 0,33 | 0,29 | 0,29 | 0,29 | 0,29 | 0,29 | 0,29 |

While preparing mortar mixtures, primarily, solid components were mixed in first two minutes period and then mixing water and superplasticizer were added and again mixed in second two minutes period. Then, the sLWA was added to mortar mixtures and mixed again in one minute period. Six mortar bars (25.4 x 25.4 x 279.4 mm) and twelve cube samples (5 x 5 x 5 mm) from every one of the mortar groups prepared according to the mixture designs were moulded and vibrated on vibration table during 120 s. The mortar bars and cube samples were cured at temperature of 23 ± 1 °C, underwater and at 40% and 100% RH conditions. Length changes of mortar bars were measured by a dilatometer with sensitivity of 2/1000 mm at 2, 3, 7, 14 and 28 days. First length values of mortar bars could be measured at 2nd days, therefore, previously shrinkage (or expansion) values were neglected.

The cube samples with saturated-dry surface (underwater and at 100% RH conditions) were weighed at 2nd and 28th days (underwater and at 100% RH). Having been weighed, the three cube samples of each group were dried at 105°C during 24 hours at the curing on the 28th day. The compressive strengths of the samples were tested and broken samples were again weighed and then these samples were put in ash-oven at 1000°C during three hours. Afterwards, these samples were cooled off until the room temperature in desiccator and were weighed again. Furthermore, the solid components added to mortar mixture were also put in ash-oven at 1000°C during three hours. The Loss on Ignition (L.O.I) values of solid components were determined and these values were subtracted from L.O.I values of samples, at rates added to the mortar mixtures by weight. In this way, the hydration degrees of mortar mixture groups were calculated /3/.

## 4. EVALUATING OF DATA

### 4.1. Shrinkage

The length changes in curing times of mortar bars were calculated according to Equation 1 /10/.

$$r = \Delta L_n / L_i \tag{1}$$

$r$ : Shrinkage of mortar bar (%)
$\Delta L_n$ : Length change of mortar bar at n. day (mm)
$L_i$ . Initial length of mortar bar (mm)

The length change of mortar bars were calibrated with adjustment rod and were adjusted using Equation 2.

$$\Delta L_n = (L_i - a_i) - (L_n - a_n) \tag{2}$$

$\Delta L_n$ : Length change of mortar bar at n. day (mm)
$L_i$ : Initial length of mortar bar (mm)
$L_n$ : Length of mortar bar at n. day (mm)
$a_i$ : Initial length of adjustment rod (mm)
$a_n$ : Length of adjustment rod at n. day (mm)

The shrinkage (or expansion) rates of mortar bars were calculated using Equation 1 and considered arithmetic average of shrinkage (or expansion) values belonging to two mortar bars. According to curing condition, the shrinkage (or expansion) rates of mortar bars belonging to each mixture group are given in Figure 2 and Figure 3.

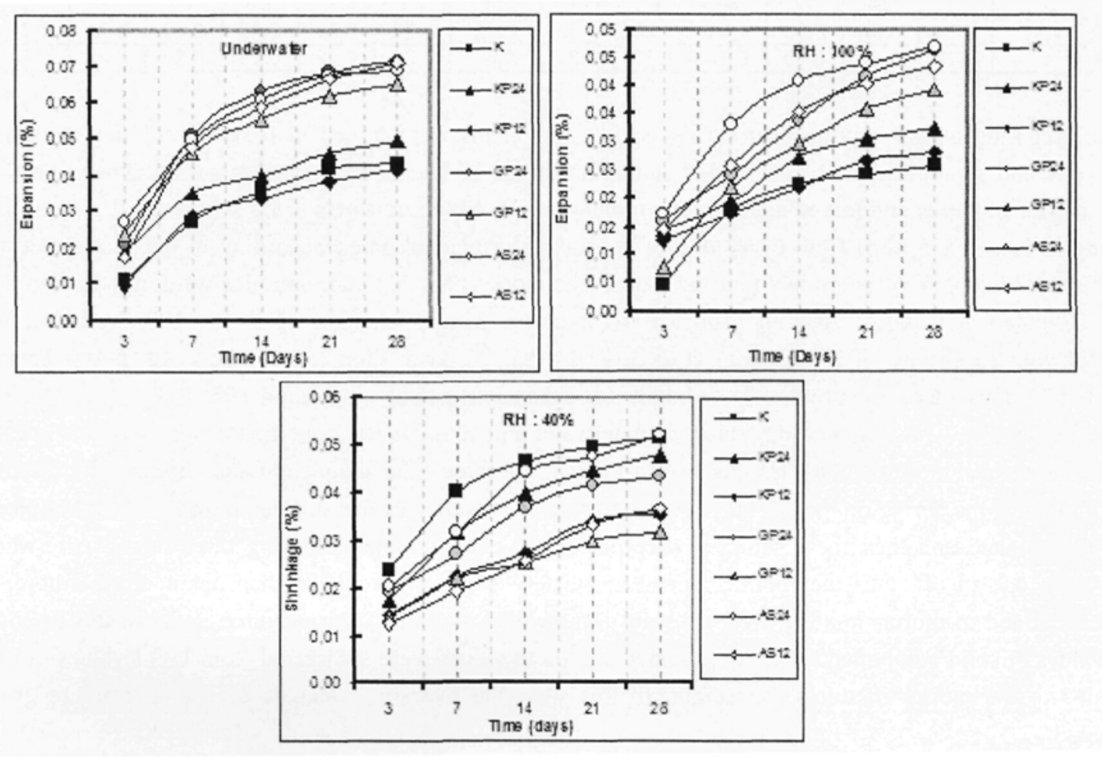

**Fig. 2:** Expansion or shrinkage rates of control mortar bars and sLWA added mortar bars ($w_t/c=0.29$) were cured underwater, at 100% and at 40% RH conditions.

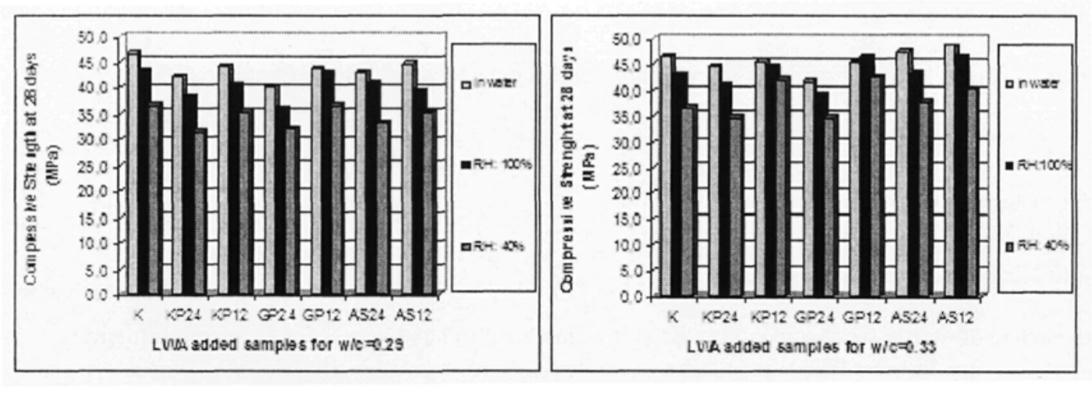

**Fig. 4:** Compressive strength at 28 days of control cube samples and sLWA added cube samples ($w_t/c=0.33$) according to curing conditions.

All of the mortar bars expanded underwater and at 100% RH conditions (as seen in Fig. 2-3). A few researchers mentioned that concretes having low w/c ratio expand during underwater curing and this situation are valid for mortar bars having to 40x40 mm dimension and smaller cross-section /9/. Maximum shrinkage value occurred at mortar bars of K group at 40% RH condition. Minimum shrinkage value was observed at mortar bars of GP12 group ($w_t/c=0.33$) at 40% RH conditions. The average shrinkage value of GP12 group mortar bars improved at 56.7% rate compared to K group mortar bars (Fig. 3). The shrinkage improvement of GP12 group samples including less LWA (as volumetric) is at level of 38.3% (as seen in Fig. 2).

### 4.2. Compressive Strength

Compressive strengths data of cube samples belonging to whole mixture groups during the curing time of 28 days are shown in Figure 4. The compressive strengths of samples including sLWA at a high rate ($w_t/c=0.33$) increased when compared to samples including sLWA at a low rate ($w_t/c=0.29$) among the samples cured at three different conditions. The compressive strengths of samples including sLWA at a low rate deteriorated when compared to compressive strengths of K samples. The compressive strengths of GP12, KP12 and AS12 ($w_t/c$) samples when compared to K samples at 40% RH increased at rates of 6%, 5% and 3%, respectively. The similar relation can be mentioned for the shrinkage values of mortar bars including sLWA at a high rate. However, improvement of both shrinkages and compressive strengths of these samples depend on homogenous distribution as related to grain size of sLWA within the concrete matrix and hydration degrees of cement paste (Table 6-7, Figure 5).

**Table 6**

Comparison of compressive strengths of K and GP12 cube samples and shrinkage rates of K and GP12 mortar bars ($w_t/c=0.33$)

| Samples | Shrinkage *(r)* | | Improving Rate (%) | Compressive Strength ($\sigma_c$) | | Decreasing Strength (%$\sigma_d$) | Improving Rate (%) |
|---|---|---|---|---|---|---|---|
| | Curing under-water (mm/m) | Curing at 40% RH (%) | | Curing under-water ($\sigma_{c1}$) (MPa) | Curing at 40% RH ($\sigma_{c2}$) (MPa) | | |
| K | $^{(1)}$ | 0,051 | 56,86 $^{(2)}$ | 46,58 | 36,69 | 21,23$^{(3)}$ | %7,08$^{(3)}$ |
| GP12 (0,33) | $^{(1)}$ | 0,022 | | 45,27 | 42,46 | 6,21$^{(3)}$ | |

*(1) It wasn't considered to expanding values of mortar bars.*

*(2) Improving rate for shrinkage (%) = $(r_K - r_{GP12}) * 100 / r_K$*

*(3) $\%\sigma_d = (\sigma_{c1} - \sigma_{c2}) * 100 / \sigma_{c1}$*

(4) Improving rate for decreasing strength = $(\%\sigma_d)_K - (\%\sigma_d)_{GP12}$

**Table 7**

Change in weights and water amounts of cube samples according to curing conditions

| **Sample** | **Weight Change $^{(1)}$ (%)** | | | **Evaporable Water Amount (by weight, %)** | | | **Non-evaporable Water Amount (by weight, %)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | under-water (+)$^{(2)}$ | (+)$^{(2)}$ | at 40 %RH(-)$^{(2)}$ | under-water | at 100 % RH | at 40 % RH | under-water | at 100 % RH | at 40 % RH |
| **K** | 1,38 | 0,85 | 1,73 | 3,45 | 3,90 | 2,54 | 5,43 | 4,45 | 3,23 |
| **$w_t/c = 0.29$** | 1,73<br>2,14 | 1,09<br>1,64 | 0,08<br>1,53 | 5,04<br>5,12 | 4,80<br>6,01 | 2,58<br>4,77 | 4,92<br>5,59 | 4,60<br>5,19 | 3,23<br>4,18 |
| **$w_t/c = 0.33$** | 3,70<br>5,75 | 1,35<br>1,86 | 1,65<br>2,38 | 5,71<br>6,89 | 6,02<br>8,52 | 3,09<br>5,06 | 5,05<br>5,66 | 4,94<br>5,59 | 3,53<br>4,48 |

*$^{(1)}$ Weight change of the saturated-dry surface samples at curing time between 3 and 28 days*

*$^{(2)}$ (+) absorbed water into concrete structure from surrounding; (-) Evaporated water from concrete structure*

### 4.3. Unit Weight and Water Content of Concrete Samples

Minimum and maximum weight changes of cube samples related to curing conditions at 3 and 28 days are given in Table 7. Initially, average mixing water content of K samples is 7.5 % by weight. This value is 8.9% for samples including sLWA at low rate ($w_t/c= 0.29$) and 9.95% for samples including sLWA at high rate ($w_t/c= 0.33$). The water loss of samples was 25% rate at 40% RH by means of evaporation (as seen in Table 7). An important part of this loss is water holding on to outer surface of samples, therefore, the effect of water loss to shrinkage improvement can be neglected. Capillary and bound water rates (by weight) of samples including sLWA at high rate increased when compared with other two groups (Table 7). This situation is supported by the results of shrinkage measurements.

### 4.4. Hydration Degrees of Concrete Samples

Portland cement components are tri-calcium silicate ($3CaO.SiO_2$), di-calcium silicate ($2CaO.SiO_2$), tri-calcium aluminate ($3CaO.Al_2O_3$) and tetra-calcium aluminum ferrite. The process by which cement components reacts with water is termed hydration. In cement, this involves many different reactions, often occurring at the same time. In the hydration reaction, the products of the cement hydration are ettringite ($3CaO.Al_2O_3.3CaSO_4.31H_2O$), portlandite ($Ca[OH]_2$), tobermorite ($CaO.SiO_2.H_2O$). As the reactions proceed, the products of the cement hydration process gradually bond together the individual sand and aggregate grains, and other components of the concrete, to form a solid mass. Theoretically, 24.16 g of water per 100 g of cement is needed to fully hydrate the cement particles. However, in practice any time the cement particles are not 100% hydrate. Cement particles in the ability to react with water is defined as hydration degree ($\alpha$). Increasing the hydration degree of cement paste, pore volume of the concrete reduces. As a result, the concrete strength increases.

In this study, the hydration degrees of concrete samples are determined as follows:

- Quartz sand having minimum lost on ignition ($LOI \cong 0$) was used as aggregate in mortar mixtures.
- After compressive strength tests were completed, concrete parts were collected.
- The pieces of concrete tested for non-evaporable water content. Measurements were performed for all mortar mixtures and curing conditions at 28 days of age.
- The amount of non-evaporable water is defined the mass loss per gram of portland cement, measured between the temperatures of 105 °C and 1000 °C.

From the non-evaporable water content, the degree of hydration can be estimated assuming a value for the non-evaporable water content of a fully hydrated sample. This value was used for calculation of hydration degree as 0.2416 g $H_2O$/g cement. One sample of each mortar or curing condition was crushed with a pestle. The powder was flushed with methanol twice to stop hydration. Three crucibles were partially filled with 50 g of powder taken from each sample and dried overnight at 105 °C. The crucibles were subsequently weighed and fired in the furnace at 1000 °C for about 3 h. The difference between the three weights, compensated for the loss on ignition of the dry cement powder of the LWA gave the non-evaporable water content of the sample. In Table 7 and Figure 7 the hydration degrees of samples, calculated from non-evaporable water amount, are shown /3/.

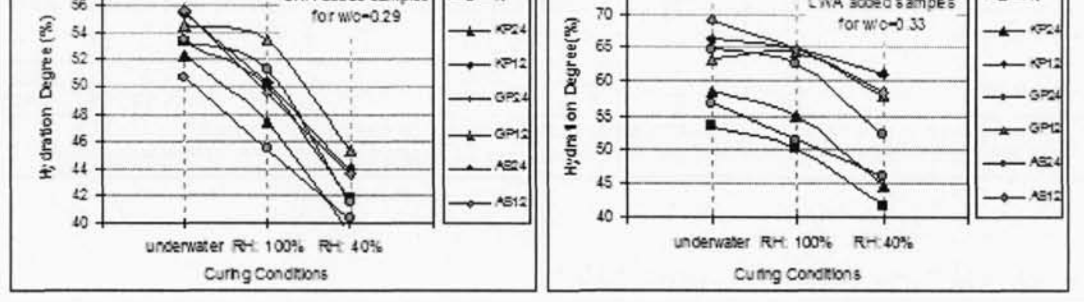

**Fig. 5:** Change in hydration degrees of concrete samples at 28 days according to curing conditions.

The changes of hydration degrees of samples at 28 curing time related to curing conditions are shown in Figure 5. At 40% RH, hydration degree improvements of GP12, KP12 and AS12 from samples including sLWA at low ratio ($w_t$/c =0.29) are not enough when compared to K samples. But, it can be said that hydration degrees of GP12, KP12 and AS12 from samples including sLWA at high ratio ($w_t$/c =0.33) improved at 16% and 20% rates. The improvements of shrinkage and compressive strength of the mentioned samples can be depended on the improvements of hydration degree. This expression will be more an accurate approach.

But, the expected improvements for hydration degrees of KP24, GP24 and AS24 samples including sLWA at high rate were not obtained. This situation was depended on the decrease at the ratio of approx. 1/8 of grain numbers and the decrease at the ratio of ½ of surface area of grains in the unit volume of grain size increased LWA (average double). It was also depended on the increase in distance among grains of LWA used as internal water reservoirs within the concrete matrix. At 40% RH, hydration degrees of GP12, AS12 and KP12 samples ($w_t$/c=0.33) are 57.9%, 58.5% and 61% rates, respectively. Although GP has maximum rate of water absorption among all of the LWA groups, the maximum improvement of hydration degree was obtained in the samples used AS aggregates. This situation can be related with the high closed pore rate and the pore structure of Gelincik pumice. Because, the closed pore structure of GP restricts water transfer to concrete matrix from the pores.

## 5. CONCLUSIONS

According to the research findings, the following conclusions are given as summarized:

- The using sLWA at the high rate (6.5 % by volume) in mortar bars and cube samples provided the improvements of shrinkage, hydration degree and compressive strength at rates of 51%, 20% and 7%, respectively at 40% RH condition.
- At the improvement mentioned above, sLWA having the greater pore sizes and having the lower rate of closed pores for 1-2 mm grain size are more active.
- Using sLWA at the low rate (3.3 % by volume) is not beneficial.
- When the unit weight change of the cube samples is investigated, the measured shrinkage can be called as "autogenous + chemical shrinkage" rather than hydraulic shrinkage that occurred in consequence of evaporation.
- Compared with K samples, the autogenous + chemical shrinkages of AS12, KP12 and GP12 samples ($w_t$/c=0.33) decreased. The improvement of hydration degrees of these samples was related with supply of water that is needed for gel phases by sLWA.

Nevertheless, the saturation of the most of LWA types is a difficult process. This situation can be an important problem for using sLWA as internal water reservoirs in HPC and other composites. To obtain sLWA, selection of the most suitable vacuum method and adaptation of this method to civil industry can be an important step for solving the problem.

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