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# Utilization of pumice of Burdur region and zeolite of Bigadiç-Balıkesir region as fine aggregate in construction materials

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*Research Article*

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**ABSTRACT**

Volcanic originated pumice and zeolite aggregates have low density owing to their considerable porous structure. Porosity is usually correlated with insulation properties. In order to examine the effects of this lightweight aggregates on dead load of structure and insulation properties of standard construction materials, samples were produced by using pumice and zeolite at varying percentages by volume and control samples were manufactured with crushed sand. The samples were exposed to normal (standard) curing, hot water curing and steam curing to observe the effect of different curing regimes on their behavior. Bulk density and thermal conductivity tests were carried out on samples. Both bulk density and thermal conductivity values of the lightweight mortar samples were smaller than those of control sample. Besides, chemical compositions of aggregates and cement, analyses were also performed. Silica content of pumice and zeolite were %54,09 and %75,14 by mass respectively.

## 1. Introduction

Cement, aggregate and water are the main components of most used construction materials namely concrete and mortar which are also called cement based materials (CBM). Aggregates have the largest share of % 60-70 by volume in CBM mixtures and any of their properties such as density, porosity, strength, durability, chemical structure directly affect CBM properties. Crushed stone and sand are the common used aggregates in conventional CBM due to their abundance beside their beneficial properties. However, their density values are between 2,60-2,70 g/cm$^3$ and with the improvements in structural engineering, high buildings have begun to be constructed and dead load were becoming more of a problem than in the past. In addition to this, the majority of the human population have started to live in the metropolitans and given birth to vertical architecture. As a result, the protection of the private area has become difficult and the sound insulation has come to the forefront. From an environmental point of view, too much energy is consumed to heat and cool the buildings, thus increasing the carbon dioxide emission (Koçkal, 2016). Recent studies have been carried out by researchers on construction materials which had low density and functional for heat and sound insulation (Patnai et al., 2015, Degrave-Lemeurs et al., 2018).

Materials used for improvement of CBM properties demonstrate considerable diversity. Zhang and Poon (2015) used lightweight expanded clay aggregate to reduce the density of CBM and furnace bottom

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ash for producing thermal insulation properties. As far as their conclusions, lightweight expanded clay aggregate CBM containing furnace bottom ash is suitable for structural use and with the increase of furnace bottom ash thermal conductivity decreased. In terms of improving thermal properties of CBM, some researchers used waste materials such as pet and rubber pieces (Yeşilata et al., 2009) and in other study was carried out to use coconut fibres in order to prevent effect of solar heat radiation (Mintorogoa et al., 2015). However, lightweight aggregates mostly possess structural properties besides insulation ones. Morover, plenty of natural or artificial lightweight aggregates for instance; pumice (Widodo et al., 2017), zeolite (Najimi et al., 2012), perlite (Şengül et al., 2011), vermiculite (Schackow et al., 2014), sintered fly ash (Koçkal and Özturan, 2010; Koçkal and Özturan 2011*a*, *b;* Koçkal, 2015) expanded clay (Fantilli et al., 2016) etc. were incorporated to develop CBM characteristics.

The purpose of this research is to investigate usability of volcanic originated pumice and zeolite particles as aggregate to improve bulk density and the thermal properties of mortars which are classified under CBM. Meanwhile, how different curing regimes affect these properties are also discussed.

## 2. Materials and Method

### 2.1. Materials

CEM-I 42.5 R Portland cement without any type of admixture was used as binder in the mortar mixtures, its specific gravity was 3,03 g/cm$^3$. The meaning of notation R is for rapid setting and it obligates this characteristic to be ground ultra fine and high content of $C_3S$ which is one of the four main compounds compared to conventional cements.

The pumice aggregate was supplied from Burdur (Ağlasun) region and zeolite aggregate was obtained from Balıkesir (Bigadiç) region. The location map of aggregate sources were given in figure 1. The physical properties of aggregates were tested according to ASTM C 128, ASTM C 29 and ASTM C 97. The results of specific gravity, water absorption, porosity, modulus of fineness, loose and rodded unit weight were given in a previous study (Beycan and Koçkal, 2017). According to TS EN 933-1 and ASTM C-136, sieve analysis of aggregates were performed and the results are given in table 1.

It is clearly noticed that all the aggregates were smaller than 4mm. Owing to the % 80 passing value of particles through 1-mm sieve, pumice and zeolite aggregates were accepted ultra fine aggregates. Crushed sand had the coarsest particles containing %37 of total particles under 1mm. Seraj et al. (2017) performed an investigation with different particle size of pumice aggregate and remarked that reducing particle size increased the rates of cement hydration, pozzolanic reaction, and compressive strength gain, while also increasing mixture viscosity.


Figure 1- Location map of the aggregate sources (Bigadiç and Ağlasun).

X-ray fluorescence (XRF) analysis was performed at the Izmir High Technology Institute Material Research Center. For each component, an average of 1,5 g powder sample was prepared and the SPECTRO-IQ II device was used. X-ray fluorescence (XRF) analysis was conducted to obtain chemical composition of fine aggregates and cement which are given in table 2 with loss on ignition values. The loss on ignition measures the mass loss of volatile materials such as carbon dioxide and water but also alteration level in the materials under high temperature exposure. The major oxides of pumice aggregate were $SiO_2$ and $Al_2O_3$ with the percentage of 54,09%, 21,68 by weight respectively. The major oxides measured in the zeolite aggregate were the same as those of the pumice aggregate. But the percentages were different and in order of 75,14% and 14,71. Both fine aggregates had high $SiO_2$ content. There are several studies in which minerals with high $SiO_2$ content, if they are ground as fine as cement, they can be used as cement replacement materials (Chen et al., 2017). On the other hand the major oxide of crushed sand was CaO with the percentage of 54,01%. When evaluated L.O.I. value of samples, it was seen that zeolite and crushed sand had higher values within the group.The reasons of high L.O.I. values in zeolite and crushed sand could be explained as follows: Zeolites were chemically known as aqueous alumina silicates. Coombs et al. (1997) stated that zeolites had a large number of water molecules attached to the clinoptilolite mineral. At high temperatures, the attached water evaporated and therefore the L.O.I value of zeolite was high. Crushed sand was a calcium carbonate ($CaCO_3$) originated aggregate and under high temperature exposure, $CaCO_3$ decomposed into CaO and $CO_2$. As a result of $CO_2$ output, L.O.I. value was high (Topçu and Demir, 2007).

The mineral phases of fine aggregates were detected with the help of X-ray diffraction method (XRD), which is based on the principle of breaking X-rays in a characteristic order, depending on the specific atomic sequences of each crystal phase. XRD analysis results are exhibited on figure 2 and 3. ($Si_{29,04}Al_{6,96}O_{96,40}Na_{1,92}Ca_{1,57}Ba_{0,32}K_{0,56}Mg_{0,72}$) chemical formulated clinoptilolite was the common mineral phase appeared in zeolite, quartz ($Si_3O_6$) and orthoclase ($Si_{12}Al_4K_4O_{32}$) were encountered rarely.

Clinoptilolite had microporous structure and high surface area. The basic units of the crystal structure of clinoptilolite, $SO_4$ and $AlO_4$ tetrahedrals, combined to form a secondary structure and it is illustrated in figure 4. The secondary structure united with different combinations and created a porous and channeled form. These channels and porosities constituted a significant surface area by providing void volume of 30% - 35% (Ersoy, 2000).

Major phase crystalline of pumice was feldspar ($Si_{9,04}Al_{6,96}Sr_{3,36}Na_{0,12}O_{32}$) and another mineral was coesite ($Si_{16}O_{32}$) identified in structure. Feldspar is a monoclinic crystal. Feldspars are the most common mineral in the rocks and compose nearly 60% of the earth's crust (Xu et al., 2017). When the previous studies were examined, it was seen in figure 5, the main mineral phase was feldspar in the petrographic analyzes performed on pumice (Döyen and Aksoy, 2013).

Table 1- Sieve analysis of aggregates.

| Cumulative Passing(%) | Aperture Size (mm) | 4 | 2 | 1 | 0,5 | 0,25 | 0,125 | 0,063 |
|---|---|---|---|---|---|---|---|---|
| | Pumice | 100 | 91 | 76 | 63 | 44 | 26 | 13 |
| | Zeolite | 100 | 100 | 77 | 53 | 27 | 8 | 1 |
| | Crushed Sand | 100 | 62 | 37 | 25 | 15 | 9 | 4 |

Table 2- Chemical composition of constituents (by weight%).

| Constituents | $Na_2O$ | MgO | $Al_2O_3$ | $SiO_2$ | $SO_3$ | $K_2O$ | CaO | $Fe_2O_3$ | L.O.I.[a] | T.A.M.O.[b] |
|---|---|---|---|---|---|---|---|---|---|---|
| Cement | 0,1 | 1,77 | 4,28 | 19,28 | 2,95 | 0,58 | 61,36 | 2,65 | 4,01 | 80,64 |
| P | 8,23 | 1,89 | 21,68 | 54,09 | 0,18 | 6,10 | 4,03 | 2,48 | 3,55 | 75,77 |
| Z | <0,11 | 1,22 | 14,71 | 75,14 | 0,01 | 2,80 | 4,21 | 1,28 | 10,94 | 89,85 |
| CS | 0,08 | 1,02 | 0,64 | 3,94 | - | - | 54,01 | 0,11 | 40,81 | 54,01 |

[a] Loss on ignition

[b] Total amount of major oxide

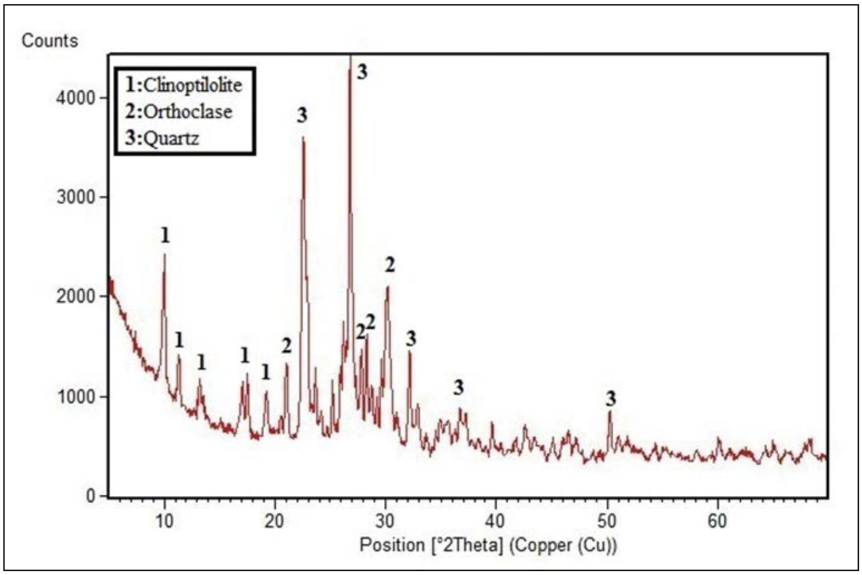

Figure 2- XRD patterns of zeolite.

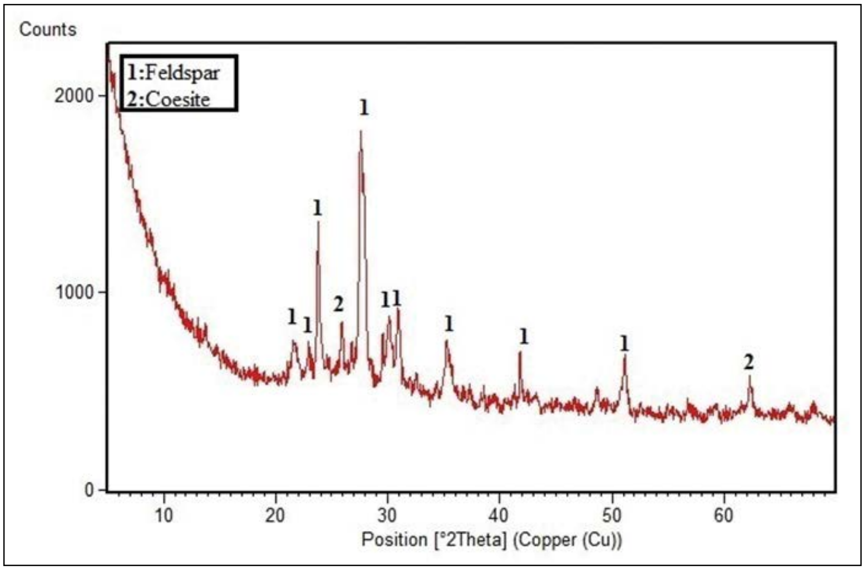

Figure 3- XRD patterns of pumice.

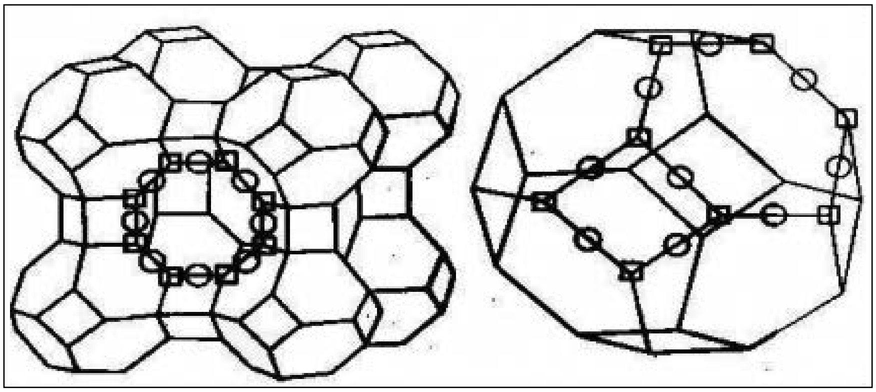
Figure 4- Connecting zeolite to tetrahedral (Akay et al., 2018 figure 1).

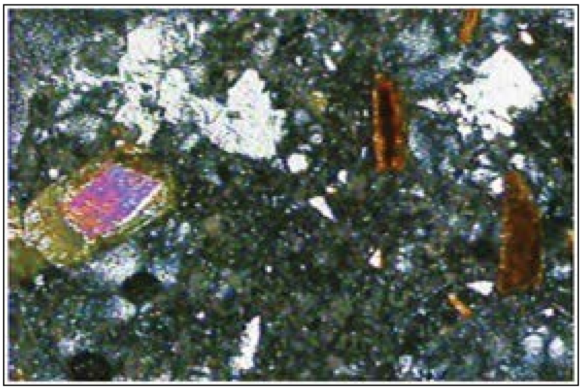

Figure 5- Feldspar mineral in pumice sample (gray) (Döyen and Aksoy, 2013).

Bilgin and Kantarcı (2018) investigated the technologic properties of zeolite formations in Balıkesir Bigadiç region. Three different zeolite samples were examined and in XRD analyzes the main mineral phase was found to be clinoptilolite. However, in petrographic analysis, quartz minerals were more visible (Figure 6).

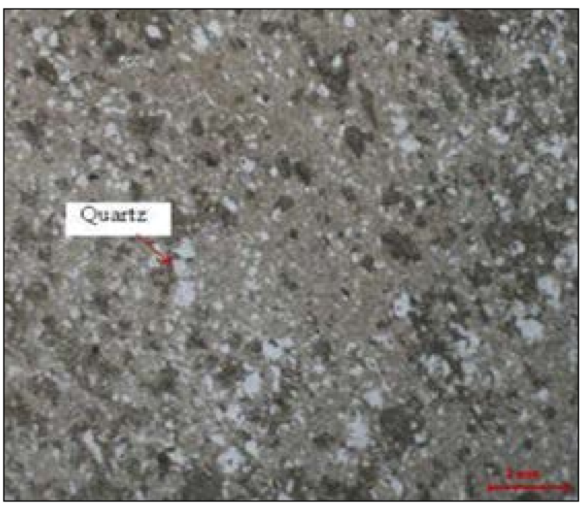


Figure 6- Quartz mineral in zeolite sample (Bilgin and Kantarcı, 2018).

Zeolite and pumice aggregates were used with five different replacement ratios by volume in mortars (Table 3). With the guidance of trial mixes, the pumice aggregate was put into mixtures in saturated surface dry condition for proper workability. The zeolite aggregate was in air dry condition before mixing and additional water for absorption was introduced into the mixture. Water-cement ratio was selected as 0.6, so that the cement paste could surround the aggregate surface and maintain sufficient workability. The cement content was kept constant as 300 kg/m$^3$ in all mixtures.

Mortars were placed into the 40x40x160mm prismatic steel molds, after demoulding at 24h, the samples were exposed to three different curing regimes; normal curing (NC), hot water curing (HC) and steam curing (SC). NC samples were maintained in a lime saturated water tank to cure at 20 ± 2°C for 7 days, HC samples were immersed 60°C in lime saturated water for 2 days and at the end of that exposure then placed into NC tank in until 7th day, SC samples were stored in steam curing cabinet at 90% relative humidity (RH) and 50°C for 7 days.

Table 3- Mix design ratios of mortars.

| Design Code | Replacement Ratio by Volume (%) | | |
|---|---|---|---|
| | Zeolite | Pumice | Sand |
| A | 70 | 30 | – |
| B | 60 | 40 | – |
| C | 50 | 50 | – |
| D | 40 | 60 | – |
| E | 30 | 70 | – |
| CS | – | – | 100 |

## 2.2. Experimental Methods

The unit weight test on fresh mortars was performed as follows: The fresh mortar was poured into container in two stages and in every stage it was rodded 25 times with a steel bar. After that, the container was weighed and achieved the result by dividing this weight to the volume.

The workability of mortars were measured with ASTM C230 flow-table test (Figure 7). The mortar was placed into special cone specified in the standard. Afterwards the cone was raised upward slowly and the arm was rotated for certain times to spread the mortar on the table. The flow diameter was obtained by measuring the diameter from both x and y axis and taking the average of them.

The bulk density values were obtained by testing 40x40x160 mm prism samples according to ASTM C 642 (Figure 8). Oven dry (OD) bulk density and saturated surface dry (SSD) bulk density were calculated below:

$$OD = W1 / (W2 - W3) \quad (1)$$


Figure 7- The workability test aparatus.


Figure 8- The test set up for determination of bulk density.

SSD= W1/(W1-W3) (2)

W1 is the mass of oven-dried sample in air (g), W2 is the mass of surface-dry sample in air (g) and W3 is the mass of surface-dry sample in water (g) (Koçkal, 2016).

Thermal conductivity values of mortars were determined by the guarded hot plate method ASTM C 177. The side surfaces of the samples were covered with glass wool to prevent heat scattering. In this experiment, thermographic camera was used to monitor the temperature difference of thermally insulated sample surfaces until a constant temperature value has been reached (Figure 9).

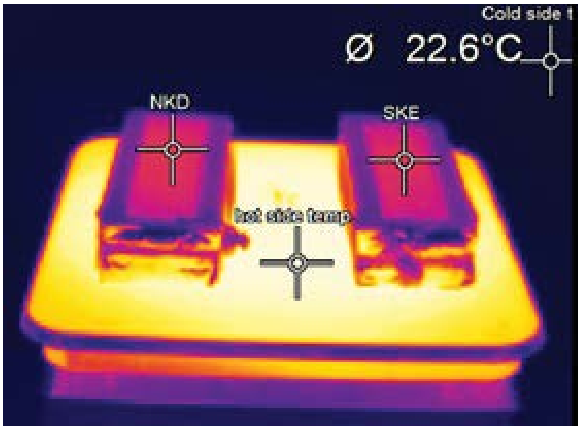

Figure 9- Thermographic camera image of mortars with different lightweight aggregate combinations.

The thermal conductivities of the samples were calculated relatively according to the control sample herein below:

RTC=((HST-CCS)x100)/CM (3)

RTC is the relative thermal conductivity (%), HST is the hot side temperature and kept constant at 100°C, CCS is the constant temperature of the steam cured control sample top surface temperature (°C). CM is the constant temperature top surface of lightweight mortar sample (°C).

## 3. Results and Discussion

The flow-table test results and unit weight values are given in table 4. With the increase of pumice aggregate ratio, unit weight values increased smilarly, in contrast to flow diameter. However, compared to the control sample all lightweight mortar samples had lower unit weight and better workability. Gündüz and Uğur (2005) reported that using fine and coarse pumice aggregate reduced the unit weight of conventional CBM and in addition to this, the elasticity modulus was decreased in contrast to the capability of energy absorbsion namely toughness.

On the other hand, the reason of better workability with increasing zeolite volume was attributed to mixing procedure. The zeolite aggregates absorbed water was added into the mixing water and this fact directly affected fresh properties of mortars. Besides, some researchers indicated that in some cases, incorporation of zeolite reduced fresh properties of CBM such as the value of flow table test and V box test. The results of workability properties of CBM including natural zeolite, carried out by Ramezanianpour et al. (2015) and they showed that use of natural zeolite increased water demand of CBM. Ranjbar et al. (2013) investigated the effect of using zeolite as a replacement material with cement on fresh properties of self compacted CBM. According to the experimental results, zeolite which was ground as fine as cement, impact workability negatively.

Table 4- Physical properties of fresh mortars.

| Mix | Unit Weight (g/dm$^3$) | Flow Diameter (cm) |
|---|---|---|
| A | 1765 | >25 |
| B | 1814 | 15,75 |
| C | 1817 | 14,4 |
| D | 1843,7 | 14,35 |
| E | 1866,5 | 14,26 |
| CS | 2421,9 | 12,4 |

SSD bulk density and OD bulk density values are shown in figure 10 and 11. SSD bulk densities of lightweight mortars were varying from 1,755 to 1,879. Morover, the positive effect of lightweight aggregates is perfectly seen with OD bulk density values between 1,358 and 1,575 when compared with the value of control sample which is 2,177. SCA mortar had the lowest SSD and OD bulk density. Actually, the samples produced with same aggregate combination ratio, generally had the lowest both SSD and OD bulk density when they were cured in steam curing. Ba et al. (2011) carried out a study on the development of voids and pore characteristic of samples exposed to steam curing for different durations. According to the mercury intrusion porosimetry method, coarse porosity increased with duration of initial steam curing.

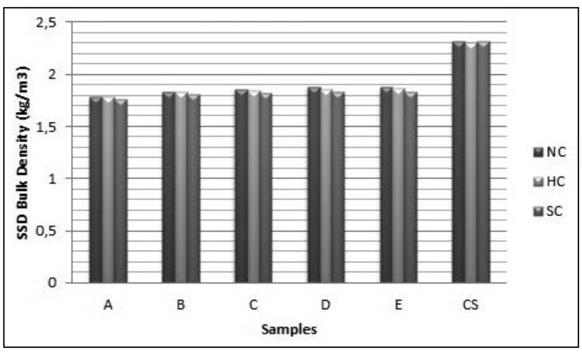


Figure 10- SSD bulk density values.

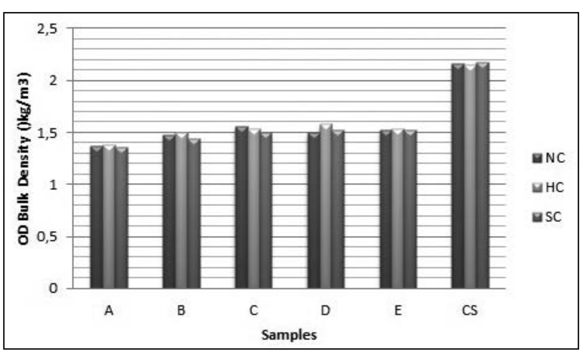


Figure 11- OD bulk density values.

Owing to increasing pumice aggregate volume in mortar samples, bulk densities increased. Hot water curing regime especially affected OD bulk density of in a positive manner. Arel (2016) remarked that hot-water curing regime affects compressive strength initialy more pronounced than steam and standard curing regimes. It can be deduced from this explanation that hot water curing regime contributes to the formation of absolute structure. Another parallel research was published by Koçkal et al. (2018). They noticed that the mechanical properties of mortars such as flexural and compressive strength were increased with the increase of OD bulk densities of mortars.

Relative thermal conductivity test results are illustrated in figure 12. Because of the thermal conductivity increases in accordance with the amount of moisture (Young, 1988), before the experiments, the samples were kept in 90 °C heated oven for 24h to evaporate pore water. OD bulk density values were in a correlative relationship with the relative thermal conductivity values of the samples. SCA sample with the smallest OD bulk density had the lowest relative thermal conductivity value.

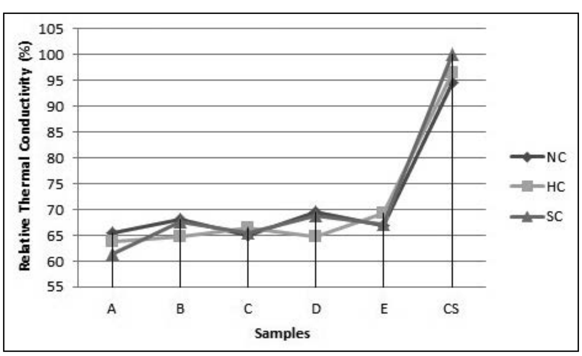


Figure 12- Development of relative thermal conductivity of mortars subjected to different curing conditions.

The lowest and the highest relative thermal conductivity values were 61,30% and 69,55% respectively. It can be seen that the aggregate type had an influence on thermal properties of mortars and pumice aggregate concentration was directly proportional to the relative thermal conductivity of mortars (Zhu et al., 2015). Even though, among lightweight mortars, the relative thermal conductivity increased with the incremental ratio of pumice, the thermal properties were better than the control mortars. The study was arranged by Amel et al. (2017) supporting that fact. The researchers prepared CBM samples with dune sand and pumice aggregate. The heat transfer and bulk density values of CBM samples were decreased with increasing rate of pumice aggregate.

The samples including high volume of zeolite aggregate, had lower relative thermal conductivity. Porosity is generally correlated with thermal conductivity. Nagrockiene and Girskas (2016) examined the properties of CBM modified with natural zeolite addition and it is stated that natural zeolite increased the closed porosity.

## 4. Conclusions

Following conclusions can be drawn from the experimental study:

- Volcanic originated lightweight aggregates can be preferred in special applications to produce building materials with special qualities.
- Utilisation of pumice and zeolite as fine aggregate resulted benefits in fresh properties of mortars. According to the value of flow table test, workability of lightweight mortars were improved resulting in reduction of labor demand and costs.
- Both OD and SSD bulk density of the lightweight mortar samples were smaller than those of control sample. Thus, zeolite and pumice aggregate can be used as an alternative construction material to reduce the self weight of structures.
- There was a corelation between OD bulk density and relative thermal conductivity values. SCA sample with the smallest OD bulk density had the lowest relative thermal conductivity value.
- The relative thermal conductivity values of lightweight mortars were approximately 40% smaller than those of the control sample. On the other hand, there wasn't any proof about the significant effect of different curing regimes on the relative thermal conductivity.

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