Research Article

Mechanical Properties and Thermal Conductivity of Aerogel-Incorporated Alkali-Activated Slag Mortars

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Compressive strength, thermal conductivity coefficient, and porosimetric properties of alkali-activated slag (AAS) mortars containing silica aerogel were investigated experimentally in this study. For this purpose, slag mortar mixtures at 0.75% and 1.0% aerogel content ratios were prepared, and these mortar mixtures were activated with lithium carbonate (Li_2CO_3) at 0.03% and 1.50% dosage rates. Mortar samples were exposed to curing process in water for 2, 7, and 28 days, and the samples, which completed the curing stage, were subjected to the compressive strength test. The porosimetry test and the thermal conductivity coefficient measurement were carried out following the compressive strength test on 28-day samples. The varying aerogel content rate in the mixtures and the effects of the dosage of Li_2CO_3 on the gel, capillary, and macropore distributions, and the effect of changing porosimetric properties on compressive strength and thermal conductivity coefficient were analyzed in detail. Experimental studies have shown that AAS mortars including an optimum 0.75% aerogel content rate and 0.03% Li_2CO_3 activation provided a compressive strength of 34.1 MPa and a thermal conductivity coefficient of 1.32 W/mK. Aerogel addition provides a partial compressive strength increase at 7- and 28-day samples while it also causes maximum strength loss of 5.0% at 2-day samples.

1. Introduction

Despite its many useful functional and economical features such as low energy and cost requirements during its production and ensuring an easy production of the structural element in building construction, cement makes a negative contribution to global warming by creating 5–8% of CO_2 emissions [1]. Therefore, it is required to use the environment-friendly, easy to recycle materials with low CO_2 emissions in material technology and to improve the environment-friendly properties of existing materials, as such in all sectors [2]. For this purpose, blast furnace slag which can be characterized as a waste-type binder can be replaced by the clinker in the binder matrix by means of its features including high sulfate resistance, high ultimate strengths, and low CO_2 release in particular [3].

In cement technology, composite binders with reduced clinker ratio have been designed by partial replacement of clinker through supplementary materials such as pozzolan,

granulated blast furnace slag, and limestone for many years. In general, significant losses are observed especially at long-term mechanical strengths at replacement of 50% or more. Thus, alkali-activated alternative binder materials of which mechanical strengths are improved by means of alkali activators are needed [4].

Alkali-activated slag is a kind of binder which is formed with the chemical reaction of an activator and a slag precursor, especially in countries where slag production is prevalent [5]. Although it has found wide use in recent years, it has not entered the regulations of most countries as a different design material from cement yet [6].

The main hydration products in alkali-activated slag mortars consist of calcium aluminosilicate hydrate gels at low Ca/Si rates, hydrocalcite, and other mineral phases [7]. The anion type of the selected alkali activator is vital in the development of mechanical strengths and the setting time, especially when the pH value exceeds 12 [8]. Both initial and

final setting times are shortened with the increase in activator dosage [9].

In alkali-activated slag mortars, with increasing activator dosages, higher compressive strengths are observed in addition to shortening setting times. The amount of replacement by weight within the binder material is also vital on the compressive strengths of the waste-activated mortars. Najimi et al. activated the 30%, 50%, and 70% slag-incorporated binder using sodium hydroxide (NaOH) and sodium silicate solutions in their experimental study. In 28-day compressive strength tests, the strength was found to be varying from 20.9 to 43.2 MPa [10].

Aiming to obtain cement-like strengths in slag mortars, different porosimetric parameters are determined compared to cement mortars. Alkali-activated slag mortars have a different pore structure than conventional cement mortars. The total porosity value of the Na_2SiO_3 -activated slag mortar at the third day might be lower than the total porosity value of the conventional cement mortar at the ninetieth day [11]. Pore volume of micropores increases and capillary pores decreases with the increment of slag content in alkali-activated slag mortars compared to conventional cement mortars [12]. In experimental studies of Shi et al., the pore diameters above 100 nm represent 11.45% of total pore volume in cement mortars, while the proportion is only 3.92% of total pore volume in alkali-activated slag mortars [13].

Experimental studies with ecological purposes for reducing the requirement for conventional cement are not conducted only due to the high CO_2 release of the cement but also for the conservation of energy by lowering the high thermal conductivity coefficient detected in the cement mortars. In order to carry out this task, the coefficient of thermal conductivity can be reduced in mortars by means of forming a suitable pore structure in cement matrix with additive materials having the low thermal conductivity coefficients. Pore structure designs could be made up to the level of "foam concrete" depending on thermal conductivity-compressive strength optimization [14].

Polyurethane foam, phenolic foam, mineral wool, polystyrene, fiberglass, rock wool polystyrene, cork, and so on are used as heat insulation materials in current material technology. In addition to these materials, silica aerogels firstly synthesized by Kistler in 1931 have been used as additive materials in experimental studies for insulation purposes in concrete technology in recent years. Considering the thermal conductivity coefficients of other insulation materials are in the range of 0.018–0.048 W/mK, the silica aerogels have extremely superior thermal insulation ability for a solid material with very low thermal conductivity coefficients (0.0034–0.022 W/mK) [15–17]. The lightness and low-volume structure of the aerogels make silica aerogels attractive compared to all other fibrous and foam-based insulation materials besides their high durability properties [18].

In previous studies, it was stated that aerogel particles are stable during the hydration of cementitious materials and aerogel particles are not degraded by the process of hydration. However, the mortar compressive strength and

TABLE 1: The physical properties of the aerogel used in the experiments.

Surface area (m^2/gr)	790–840
Pore diameter (nm)	8–10
Porosity (%)	>94%
Apparent density (kg/m^3)	90–100
Surface group	–OH

TABLE 2: Chemical composition of Li_2CO_3 .

Component	(%)
Li_2CO_3	Minimum 99
Cl	Maximum 0.02
Na_2O	Maximum 0.20
CaO	Maximum 0.05
Fe_2O_3	Maximum 0.01
SO_4	Maximum 0.20

thermal conductivity coefficient decrease in proportion to the increase of aerogel content [19].

In this study, unlike previous experimental studies, aerogel contribution was made to alkali-activated slag (AAS) mortar instead of conventional cement mortar, and it was added at the rates of 0.75% and 1.0%. Alkali activation was performed by activation of slag mortar with lithium carbonate (Li_2CO_3) in order to minimize the probable compressive strength losses that could be caused by the lower activation ability of the slag material representing the half of the composite binder material compared to the clinker.

2. Materials and Methods

2.1. Materials

2.1.1. Binder. Composite binder material, which consists of CEM I type 42.5R Portland cement and granulated blast furnace slag with 50% by weight for each, was preferred in the mortar mixture produced within the scope of experimental studies. Granulated blast furnace slag and Portland cement are supplied by Bolu Cement Co.

2.1.2. Sand. Standard Rilem sand, which is packed and supplied from Bolu Cement Co., was used in mortar mixtures. The density of sand used in the experiments was determined as $1.352 \text{ kg}/\text{dm}^3$, and the specific gravity was 2.563.

2.1.3. Aerogel. Silica-based hydrophilic aerogels are used to increase thermal insulation in mortar mixtures. Silica aerogel was produced by Ensate Yalıtım Mühendislik Proje San. Tic. ve Ltd. Şti and supplied from the same company. The physical properties of the hydrophilic aerogel are given in Table 1.

2.1.4. Lithium Carbonate. Lithium carbonate (Li_2CO_3), which is rarely used in previous experimental studies, was preferred as the alkali activator in mortar mixtures. This activator was obtained from Sorel Sanayi Ürünleri Tic.

TABLE 3: Physical composition of Li_2CO_3 .

Appearance	Free-flow powder
Humidity (%)	0.3–0.9
Unit weight (kg/m^3)	850–900
d50 granulometric analysis (micron)	Maximum 6.9
d97 granulometric analysis (micron)	Maximum 20

Ltd. Sti. In Tables 2 and 3, the chemical and physical properties of Li_2CO_3 are presented.

2.2. Mix Proportions. In the experimental studies, four mixtures of mortars were prepared for the production of alkali-activated slag mortars. Standard Rilem sand and composite binder, which consist of cement and granulated blast furnace slag, were used in all mortar mixtures. The thermal insulation target in the mortar samples was tried to be provided by the silica-based hydrophilic aerogel content at 0.75% and 1.00% rates. Slag mortars were activated with Li_2CO_3 in order to increase binding activity of the granulated blast furnace slag, which is about 50% of the binder material. Li_2CO_3 was used in mortar mixtures at the rates of 0.03% and 1.50% by weight. In mortar mixtures, 50% of the binder material used in the mortar mixtures is composed of cement while the remaining 50% of the material is designed as the sum of slag, aerogel, and Li_2CO_3 . Furthermore, the proportion of water/binder material was adjusted as 0.50 in all mixtures. Mixture ratios of the alkali-activated slag mortars are given in Table 4.

2.3. Curing Conditions and Testing. In the scope of the experimental studies, three prismatic mortar samples with dimensions of $40 \times 40 \times 160$ mm were produced for each of 4 different mixtures designed at different aerogel content rates and Li_2CO_3 dosages, and the samples were subjected to curing process in water during 2, 7, and 28 days. The samples which completed the curing session were subjected to compressive strength test through ToniTechnik brand and ToniNORM/Toni TROL model device. Mercury intrusion porosimetry and thermal conductivity coefficient measurements were carried out on the parts of the 28-day specimens, which were subjected to compressive strength, after the strength test performed in consistent with TS EN 196-1 standards that define cement strength tests.

Mercury intrusion porosimetry experiments were implemented using a Micromeritics device. Porosimetric properties of the mortar samples were determined by means of the device, and the results of strength and thermal conductivity coefficient were examined by porosimetric parameters.

Thermal conductivity coefficient measurements were carried out using a C–Therm/Tci thermal conductivity device. According to the device specifications, the thermal conductivity coefficient measurement can be carried out on specimen parts subjected to compressive strength without special sample preparation for conductivity determination. Thermal conductivity coefficient measurements were repeated five times for each specimen.

3. Results and Discussion

3.1. Setting Time Results. The setting time results of the aerogel-incorporated AAS mortars are shown in Table 5. The varying activator dosage and aerogel content are highly effective both in the initial and final setting times.

S2 and S4 specimens have the earliest initial setting times of 75 and 85 minutes and final setting times of 180 and 195 minutes, respectively. Since these samples are the highest Li_2CO_3 -dosed (1.50%) samples in experimental studies, the hydration progresses rapidly due to the effect of high activator dosage. Quite long initial setting times of the samples in S1 and S3 are related to the minimum Li_2CO_3 dosage (0.03%) in the samples.

The minor difference between the initial and final setting times of the S2 and S4 samples which have equal activator dosages occurs as a result of the difference in aerogel content rates. The S4 sample that has 1.0% aerogel content has slightly later initial and final setting times than the sample S2 with 0.75% aerogel ratio.

3.2. Compressive Strength Results. In Table 6, the compressive strength test results of aerogel-incorporated AAS mortars on days 2, 7, and 28 were presented. The compressive strengths of 2 days in mortar specimens with different aerogel content ratios and activator dosages are in the range of 12.1–14.5 MPa, while the compressive strengths of 7 and 28 days are varying within the ranges of 19.1–23.8 MPa and 34.1–36.9 MPa, respectively.

The S2 sample (14.5 MPa) with the highest compressive strength among the compressive strength results of the 2-day samples, includes 0.75% aerogel content and 1.50% Li_2CO_3 activator dosage. The S3 sample at which the minimum compressive strength (12.1 MPa) is obtained includes 1.0% aerogel additive and 0.03% activator dosage. The difference of 19.8% determined between 2-day compressive strength results on the S2 sample compared to the S3 sample occurs due to the Li_2CO_3 effect which is increasing from 0.03% to 1.50% in the mortar mixtures. Similarly, compressive strength differences of 14.1% between S1 and S2 (0.75%) samples and 15.7% between S3 and S4 (1.0%) samples with equal aerogel content is an indicator of the positive effect of increasing Li_2CO_3 dosage on the compressive strengths. Evaluating the compressive strength for the equal Li_2CO_3 dosages, the determined compressive strength losses of 4.9% and 3.5% between the samples S1–S3 and S2–S4, respectively, are related to increasing aerogel content rate in the mortar mixtures.

The S4 sample (23.8 MPa), with the highest compressive strength among the compressive strength test results of the 7-day samples, includes 1.0% aerogel content and 1.50% Li_2CO_3 activator dosage. The second sample, in which the second highest compressive strength is determined, also contains a 1.50% Li_2CO_3 dosage. S1 and S3 samples, in which the lowest compressive strengths are obtained, include 0.03% Li_2CO_3 dosages. For 7-day compressive strength test results, compressive strength difference between samples which have the maximum and minimum strengths is

TABLE 4: Mixture ratios of the aerogel-incorporated AAS mortar samples.

Mix	Aerogel (wt.%)	Li ₂ CO ₃ (wt.%)	Slag (wt.%)	Cement (wt.%)	Water/cement	Water (ml)	Sand (g)
S1	0.75	0.03	49.22	50			
S2	0.75	1.5	47.75	50			
S3	1	0.03	48.97	50	0.50	225	1350
S4	1	1.5	47.5	50			

TABLE 5: Setting time test results of the aerogel-incorporated AAS mortar samples.

Mix number	Initial setting time (minimum)	Final setting time (minimum)
S1	315	360
S2	75	180
S3	315	360
S4	85	195

TABLE 6: Compressive strength test results of the aerogel-incorporated AAS mortar samples.

Mix	Compressive strength (MPa)		
	2 days	7 days	28 days
S1	12.7	19.1	34.1
S2	14.5	22.9	36.6
S3	12.1	19.2	35.6
S4	14	23.8	36.9

24.6%. The strength increments of 0.1 and 0.9 MPa were determined between the compressive strength of S1–S3 and S2–S4 samples, which have equal Li₂CO₃ dosages, with increasing aerogel contribution.

The compressive strength test results of the 28-day samples are very similar to those of the 7-day samples. S4 and S2 samples, which have the highest Li₂CO₃ dosages, provide maximum strength values among the compressive strength results of the 28-day samples. A 0.8% difference between the compressive strength results of these two samples with the highest strength values is observed. This difference obtained in the equivalent activator dosage is important in terms of determining higher strength in the sample including higher aerogel content rate as in the 7-day compressive strength results. The positive effect of the activator dosage on the compressive strength is also evident in the results of the 28-day samples since the sample with the activator dosage of 0.03% has the lowest value with the value of S1 of 34.1 MPa. The strength increases of 1.4 and 0.3 MPa were determined between the compressive strength of S1–S3 and S2–S4 samples with equal Li₂CO₃ dosages, with incremental aerogel contribution.

3.3. MIP Test Results. The MIP test results of aerogel-incorporated AAS mortars determined at the end of 28-day curing time are presented in Table 7. The total porosity values in mortar specimens with different aerogel content ratios and activator dosages are varying in the range of 11.46–15.53%. Considering test results, median pore diameter-area values were found to change from 5.8 to 8.8 nm, and median pore diameter-volume values were observed to vary from 32.7 to 42.3 nm.

The effect of the porosity parameters (median pore diameter-volume, median pore diameter-area, and total porosity) given in Table 7 on pore size distribution of mortar samples is presented in Figure 1. In the S2 sample, in which maximum total porosity of 15.53% was detected, there are maximum porosities in the diameter ranges of 10,000–100,000 and above 100,000 nm (5.63% and 7.07%, resp.) unlike other samples. The total porosity value can reach to

15.48% in the S3 sample by means of the porosity distribution determined in the same diameter ranges (5.36% and 4.98%, resp.). The total porosity values of S1 and S4 are lower than those of S2 and S3 since there is no porosity in the diameter ranges of 10,000–100,000 and above 100,000 nm. The total porosity value of the S4 sample (13.60%) is higher than that of the S1 sample (11.46%) due to the higher porosity of the sample S4 in the range of 1,000–10,000 nm compared to that of the sample S1.

Figure 2 shows the relationship between median pore diameter-area and total porosity values in the mortar samples. The total porosity value tends to decrease due to increasing median pore diameter-area in the mortar samples. As a result of the porosimetry analysis, the highest and lowest diameters were determined on the S1 sample (8.8 nm) and on the S3 sample (5.8 nm), respectively. The minimum total porosity value (11.46%) was determined by means of the maximum diameter of the S1 sample. In S3, a very high total porosity (15.48%) was determined despite the lowest diameter. Samples S1 and S3, where the lowest and highest diameters are determined, are also the lowest Li₂CO₃-dosaged samples. In the equal Li₂CO₃ dosages, the aerogel content rate varying by 0.25% is quite effective on median pore diameters.

In Figure 3, the relationship between median pore diameter-area and median pore diameter-volume in mortar samples is shown. In the samples with 0.03% activator dosage, higher median pore diameter-volume values were obtained compared to the ones with 1.50% activator dosage despite the varying aerogel content ratio. The highest median pore diameter-volume is observed at S1 which has also the highest median pore diameter-area. Examining the compressive strengths obtained after 28-day curing time, pore diameter forming at maximum level results in obtaining the minimum compressive strengths in the S1 sample, even though the sample provides maximum the median pore diameter-area and the median pore diameter-the volume values compared to the other samples.

Figure 4 shows the relationship between the median pore diameter-volume and 28-day compressive strengths in the mortar samples. Diameter values for aerogel content rates of

TABLE 7: MIP test results of aerogel-incorporated AAS mortars.

Mix number	Median pore diameter-area (nm)	Median pore diameter-volume (nm)	Total porosity (%)
S1	8.8	42.3	11.46
S2	6	39.4	15.53
S3	5.8	39.5	15.48
S4	6.6	32.7	13.60

FIGURE 1: Content of pores in mortars.

FIGURE 2: Relation between median pore diameter-area and total porosity.

FIGURE 3: Relation between median pore diameter-area and median pore diameter-volume.

0.75 and 1.0% are at a minimum of 32 nm. The compressive strengths of the samples decrease without any exception depending on the increasing median pore diameter-volume values. Similar compressive strengths of 35.5–36.6 MPa were found in samples S2 and S3 which have also nearly the same median pore diameter-volume values of 39.4–39.5 nm. For the samples S1 and S4, the diameter difference of 9.6 nm

determined at the median pore diameter-volume value allow an increase of 8.2% in compressive strength of the S4 sample.

As a result of the increase in hydration products formed by the activator dosing which increases in equal aerogel content, the median pore diameter-volume is decreasing. The reduction of median pore diameters-volume is caused

FIGURE 4: Relation between median pore diameter-volume and compressive strength.

by the placement of the formed hydration products in the pores. Median pore diameter-volume is also reduced with the use of aerogel at a constant activator dosage. This reduction is not due to the hydration products, however, it is because of the decrease observed in diameters by the effect of increasing aerogel content. As a natural consequence of this, the median pore diameter-volume decreases and therefore the compressive strengths increase.

By evaluating pore size distributions in mortar samples, it is seen that, in Figure 5, the samples tend to behave differently depending on their total porosity values. S4 and S1 samples, which have total porosity values of 13.5% and 11.4%, exhibit a pore diameter distribution behavior that is independent of each other and S2-S3 samples, while S2-S3 samples with the total porosity value of 15.5% show similar behavior.

S2 and S3 samples exhibit similar behavior across all diameters along the graph. Unlike the other samples, pore diameters of 90,000 nm and above were found in these samples. In other samples, however, pore diameter greater than the value of about 7,000 nm was not measured. S2 and S3 samples are the ones exhibiting the highest cumulative pore volume behavior throughout all micro- and capillary pore diameter ranges. Similar cumulative pore volume-pore size distribution behavior of samples S2 and S3 is reflected in all mechanical and porosimetric parameters. The median pore diameter-volume values (39.4 and 39.5 nm), median pore diameter-area values (6.0 and 5.8 nm), total porosity values (15.53 and 15.48%), and compressive strengths (35.6 and 36.6 MPa) of the samples are quite similar.

The maximum pore diameter determined in the S4 sample is 6,670 nm. Throughout the graph, its porosimetric behavior almost coincides with the S1 sample in diameters of 1,000 nm and above, while it exhibits a lower cumulative pore volume behavior than the sample group of S2-S3. This porosimetric diameter distribution difference throughout the diameter range of 3 to 1,000 nm is reflected in the porosimetric parameters of the S4 and S1 samples.

Although the S1 sample behaves quite differently than the S2-S3 samples, it tends to exhibit a characteristic closer to the S4 sample since the highest pore diameter is detected

FIGURE 5: Pore size distributions.

FIGURE 6: Relation between compressive strength and total porosity.

about 5,080 nm. The lowest total porosity (11.46%) and the highest median pore diameter-volume (42.2 nm) values were found due to the fact that it has the lowest cumulative pore volume value among all samples and exhibits its porosimetric properties at a limited diameter range.

Figure 6 shows the relationship between total porosity and 28-day compressive strengths in the mortar samples. Regarding previous experimental studies, it is known that aerogel content does not affect the hydration level of binding material. By means of increasing activator dosage ability of increasing the number of C-S-H bonds in the cement matrix in constant aerogel content, higher compressive strengths could be determined in sample S2 than S1 and, similarly, in S4 than S3. Adhesion between the matrix of binder material and the brittle aerogel particles during hydration is highly influenced by the activator dosage. The increased activator dosage in the low aerogel content rates (S1 and S2) increases

TABLE 8: Thermal conductivity test results of aerogel-incorporated AAS mortars.

	Thermal conductivity (W/mK)
S1	1.32
S2	1.45
S3	1.46
S4	1.58

the total porosity of the mortar by increasing the volume of the transitive zone formed between the aerogel particles and the binder matrix. At high aerogel content rates (S3 and S4), this effect created by increasing activator dosage is reduced and the influence on the total porosity of the mortar is reversed. This situation is clearly observed in Figure 1 for diameter distributions of 100,000 nm and above. For this reason, the effect of increasing activator dosage ability of increasing the number of C-S-H bonds in cement matrix is more effective than the change in total porosity on compressive strengths.

3.4. Thermal Conductivity Test Results. The thermal conductivity coefficient results of alkali-activated slag mortars are presented in Table 8. In the experimental studies, the thermal conductivity coefficient results were found in the range of 1.32–1.58 W/mK.

The lowest thermal conductivity coefficient was 1.32 W/mK at S1 sample with 0.75% aerogel content and 0.03% Li_2CO_3 activator dosage. In this sample, the lowest conductivity coefficient was found due to the effect of the highest median pore diameter-volume value (42.2 nm) and the highest median pore diameter-area value (8.8 nm) differently from the other samples. Increasing aerogel content rate decreased median pore diameter-volume values (395 and 32.7 nm) in the S3 (1.46 W/mK) and S4 (1.58 W/mK) samples, respectively, and lead to higher thermal conductivity coefficients (at rates of 10.6% and 19.6%, resp.) in comparison with that in the S1 sample.

Although the S2 sample (1.45 W/mK) has the same aerogel content as the S1 sample, the pore structure of the sample is similar to the S3 sample since the median pore diameter-volume value (39.4 nm) and median pore diameter-area value (6.0 nm) are developed due to the high Li_2CO_3 dosage. Therefore, almost the same conductivity coefficient as the S2 sample could be found at the sample S3.

Figure 7 shows the relationship between the median pore diameter-area values and the thermal conductivity coefficient in the mortar samples. The thermal conductivity coefficient increases with the increment of pore diameter up to the value around 6.5 nm; however, the coefficient decreases with the increase in the diameter up to higher values. The thermal conductivity coefficients were 1.45–1.46 W/mK for samples with 5.8–6.0 nm pore diameter and 1.58 W/mK for samples with 6.6 nm pore diameter. The thermal conductivity coefficient has decreased to the minimum value when the median pore diameter-area value reached 8.8 nm for S1 sample.

Since the median pore diameter-area values of samples S2 and S3 are very close to each other, the thermal

FIGURE 7: Relation between median pore diameter-area and thermal conductivity test results.

FIGURE 8: Relation between median pore diameter-volume and thermal conductivity test results.

conductivity coefficients are also very approximate to each other (1.45 and 1.46 W/mK). It is expected that the median pore diameter-area of S1 (8.8 nm) is larger than those of S2 and S3, and the thermal conductivity coefficient is also lower. S4 has a higher thermal conductivity coefficient, even though it has a higher median pore diameter-area than S2 and S3. The case is an unexpected issue. The evaluations made considering experimental findings, however, have shown that median pore diameter-volume gives better results than those with median pore diameter-area measurements. This is an important and promising result for MIP evaluations.

Figure 8 shows the relationship between the median pore diameter-volume values and the thermal conductivity coefficient in the mortar samples. The thermal conductivity coefficient tends to decrease depending on the increasing pore diameter value. In the samples with the similar pore diameter value of 39.4–39.5 nm, the thermal conductivity coefficient was found relatively similar to 1.45–1.46 W/mK, respectively. The thermal conductivity coefficient has

FIGURE 9: Pore volume of gel pores, capillary pores, and macropores for all samples obtained from MIP data.

decreased to the minimum value when the median pore diameter-volume value reached to 42.3 nm for S1 sample.

The percentage distribution of pore volumes in the total pore volume is shown in Figure 9. In the S1 sample at which the minimum thermal conductivity coefficient was found, minimum gel pore formation (17.86%) and maximum capillary pore formation (82.14%) exist compared to the other samples. In S2 and S3 samples which have compressive strengths and thermal conductivity coefficients close to each other, macropore formation in percentages of 12.7% and 10.35% was observed. In these samples, the formation of macropore increases the maximum total porosity values of the samples to 15.53 and 15.47% compared to the other samples; however, it could not ensure to decrease the conductivity coefficients to desired values.

4. Conclusions

- (i) Increasing the aerogel content rates in equal activator dosaged samples causes negligible extension at both initial and final setting times while increasing Li_2CO_3 dosage in mortar mixtures shortens both initial and final setting times at mortar samples.
- (ii) In the compressive strength test of aerogel-incorporated AAS mortars performed for 2-, 7-, and 28-day curing times, the highest compressive strengths were obtained from the samples with high Li_2CO_3 doses (1.5%) and the lowest strength values were determined at the samples with low Li_2CO_3 doses (0.03%) for all curing times.
- (iii) Partial strength increase was found with the incrementing aerogel additive ratio at 7- and 28-day samples while increasing aerogel content causes the partial loss in compressive strengths at

2-day ones. By means of increasing aerogel content in the samples with equal dosages, the maximum strength loss measured at 2-day samples is 4.9%. However, maximum strength increases were found as 0.9% and 1.4% at 7- and 28-day strength results for equal doses and increasing aerogel content rates.

- (iv) Total porosity value tends to decrease due to the increasing median pore diameter-area value in the mortar samples.
- (v) In aerogel-incorporated AAS mortar samples, median pore diameter-volume is more influential on compressive strength and thermal conductivity coefficient than the total porosity value. Since a satisfactorily high median pore diameter-volume value could not be detected in samples with higher total porosity and macropores, a significant reduction in the conductivity coefficient was not observed.
- (vi) The compressive strengths decrease with the increasing median pore diameter-volume values. In the samples with the lowest total porosity, minimum compressive strength under the control of maximum median pore diameter-volume values was found. The diameter difference of 9.6 nm corresponds to 8.2% improvement in compressive strength.
- (vii) Minimum thermal conductivity coefficient (1.32 W/mK) was found by means of maximum median pore diameter-volume and maximum median pore diameter-area values at the 0.75% aerogel content rate and 0.03% Li_2CO_3 dosage. At these rates, gel pore and capillary pore diameter formations are at the minimum (17.86%) and maximum (82.14%) levels, respectively.
- (viii) The high correlation between compressive strength-median pore diameter-volume values remains valid in also between thermal conductivity coefficient-median pore diameter-volume values. The minimum thermal conductivity coefficient was found at the lowest total porosity value by means of the highest median pore diameter-area and median pore diameter-volume values.
- (ix) Increasing activator dosage in equal aerogel content rates brings about an increase in thermal conductivity coefficient due to the decrease in median pore diameter-volume value.

Data Availability

All data generated or analysed during this study are included in this published article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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