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Investigation of the Properties of Foam Concrete Produced Using Liquid Latex

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ABSTRACT

Foam concrete, a type of lightweight concrete, is highly preferred due to its lightness and ease of application. In addition, substitute materials are used in the foam concrete mixture in order to further improve the properties of foam concrete. In this study, the engineering properties of foam concrete produced using liquid latex were analyzed. For this purpose, liquid latex was added to the mixing water. The amount of latex is fixed at 25% of the cement weight. Additionally, the amount of liquid latex added to the mixture was reduced from the amount of mixing water. According to the results, it was determined that liquid latex made positive contributions to the engineering properties of the produced foam concrete. It was found that the water absorption value of latex-added samples decreased significantly compared to the reference sample. In addition, the thermal conductivity coefficient of the samples with latex added was lower than the reference sample. In the microstructural analysis, it was seen that the pores were more homogeneous than the reference sample and no cracks occurred. Finally, the long chain bonds formed by liquid latex in concrete were detected for the first time by SEM image analysis in this study.

Sıvı Lateks Kullanılarak Üretilen Köpük Betonun Özelliklerinin Araştırılması

ÖZ

Hafif beton türü olan köpük beton, hafifliği ve uygulama kolaylığı nedeniyle oldukça fazla tercih edilmektedir. Ayrıca köpük betonun özelliklerinin daha da iyileştirilmesi amacıyla köpük beton karışımında ikame malzemeler kullanılmaktadır. Bu çalışmada sıvı lateks kullanılarak üretilen köpük betonun mühendislik özellikleri analiz edilmiştir. Bu amaçla karışım suyuna sıvı lateks eklenmiştir. Lateks miktarı çimento ağırlığının %25'i olarak sabitlenmiştir. Ayrıca karışıma eklenen sıvı lateks miktarı, karışım suyu miktarından azaltılmıştır. Sonuçlara göre sıvı lateksin üretilen köpük betonun mühendislik özelliklerine olumlu katkılar sağladığı tespit edilmiştir. Lateks katkılı numunelerin su emme değerinin referans numuneye göre yüksek oranında azaldığı bulunmuştur. Ayrıca lateks ilave edilen numunelerin ısıl iletkenlik katsayısı referans numuneye göre daha düşük çıkmıştır. Mikroyapısal analizde gözeneklerin referans numuneye göre daha homojen olduğu ve herhangi bir çatlak oluşmadığı görülmüştür. Son olarak sıvı lateksin betonda oluşturduğu uzun zincirli bağlar ilk defa bu çalışmada SEM görüntü analizi ile tespit edilmiştir.

Anahtar Kelimeler: Lateks, zincir bağı, ısı iletkenlik katsayısı, ısı yalıtım malzemesi, köpük beton

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1. Introduction

Foam concrete (FC) is either a Portland cement paste or mortar whose unit volume weight is reduced by keeping air bubbles in it with suitable foaming agent [1-2]. FC is also called as a light cellular concrete [3]. Unlike structural concrete, FCs are widely used in applications such as thermal and sound insulation in buildings due to their excellent insulation properties, dead load reduction due to their lightweight, [4]. Density, thermal conductivity and compressive strength of FC made for insulating is roughly between 350-600 kg/m3, 0.15-0.2 W/mK and 1-6 MPa, respectively [5]. Today, while energy efficiency gains a lot of importance, interest in lightweight and heat-insulated FCs is also increasing [6]. However, in order to obtain high performances from buildings where FC is used, the density and thermal conductivity for FC should be further decreased [6].

The key factors for the engineering features of FC are the w/c (water to cement proportion), porosity, and nature of foaming agent [2,7]. The density and strength of FC are directly related to each other. [7]. Chung et al. [8] examined the void properties of FC produced at different densities. According to the results obtained, they stated that as the density increases, the size for the voids in the FC decreases and thus the compressive strength increases. In addition, Kearsley and Wainwright [9] stated that the strength is related to porosity and that high air content causes low density, low compressive strength and high porosity. Not only the density but also the foam agents used have a great impact on the strength of FCs [10].

The pores and cement paste are roughly constituents of hardened FC [11,12]. Studies [13-17] in the literature indicate that the volume fraction for solid components and geometric distribution of pores are the most important factors affecting the thermal conductivity properties of a material having the void structures. Chung et al. [18] stated that the thermal permeability property of FC is influenced by its pore properties due to anisotropic effect.

Additives used in concrete are one of the components that significantly affect the properties of concrete [19]. It has been known for many years that latex polymer compounds has been used in the concretes [20-23]. In a study [24], different types of latex were added to the foaming agent separately in order to strength the foam bubble structure. According to result, in general, the expansion rate of the foaming agent modified by the addition of latex to the foaming agent solution was increased at low concentration and the stability of the foam was doubled. In addition, this study also emphasized that the latex type used to modify the foaming agent has very strong effects on FC [24].

The properties of FC produced using liquid latex were investigated in this study. In addition, the analysis of the long chain bond structure, which enables latex to enhance the qualities of FC, has been examined in detail.

2. Material and Method

2.1. Material

2.1.1. Cement

CEM I 52.5 R type cement, shown in Table 1, was used in the study.

Table 1. The properties of the used cement

Oxide	**SO_3**	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**LOI***	**Density (g/cm^3)**
Content (%)	3.31	21.5	4.06	0.25	65.6	1.30	0.3	0.35	3.5	3.05

* LOI: Loss on ignition

2.1.2. Latex

The features of the liquid latex are given in Table 2.

Table 2. The features of the latex (Lateksin özellikleri)

Properties	**Density (g/cm^3)**	**Colour**	**Total Solid Content (%)**	**Dry Rubber Content (%)**	**Non-Rubber Solid (%)**	**Ammonia Content (Total Weight) (%)**	**Ammonia Content (Water Phase) (%)**	**pH**	**Magnesium Content (In Solid) (ppm)**
Description	0.910	Milk white	62	60	1.7	0.71	1.90	10.7	24.3

2.1.3. Synthetic-based foam additive

Table 3 shows the features of the foam.

Table 3. Properties of foam

Density (g/cm^3)	**Appearance**	**pH**
1.27	Light brown	6.2

2.2. Method

While producing FC, the slurry consisting of a mixture of cement, water and liquid latex was mixed in a helical type mixer at 60 rpm for 90 seconds. Liquid latex was added to the mixing water and added to the mixture. The amount of latex is fixed as 25% of the cement weight. In addition, the amount of latex added to mixture was reduced equally from the amount of mixing water. Foam was produced in the generator shown in Figure 1 by applying 2.5 bar air pressure to the mixture produced using the foam additive/water ratio given in Table 4 (Figure 1).

Figure 1. Foam production in a foam generator

After the prepared foam was added to the slurry, it was mixed again in a helical type mixer for 90 seconds (Figure 2). It was observed that the foam added at the end of the mixing process was completely surrounded by the slurry.


Figure 2. Adding the produced foam to the mixture in a helical type mixer

The foam produced was taken into containers with a certain volume and by adding it to the foam mixture at the calculated scale, FC was produced at the targeted density (240 kg/m³). Mixing ratios of FC are given in Table 4.

Table 4. Mixing Ratios (Karışım Oranları)

Specimens	**Density (kg/m³)**	**Cement (kg/m³)**	**Water (kg/m³)**	**Lateks (kg/m³)**	**Foam Mixture ratio (Foam additive/water)**	**Volume of foam (%)**
FC (Reference)	240	200	100	0	1 / 50	82
LFC	240	200	50	50	1 / 50	82

Abbreviations: FC: Foam concrete; L: Lateks

Fresh FC was taken into molds of 100x100x100 mm for compressive strength test and 300x300x50 mm molds for determination of thermal conductivity coefficient . All specimens were subjected to air curing at room conditions until the test days. The compressive strengths of the specimens on days of 1,3,7 and 28 were tested to according to TS EN 12390-3 [25]. In addition, the thermal conductivity coefficients of the 300x300x50 mm specimens aged 28 days were measured according to ASTM C-5218-21 [26].

In order to test the water absorption of all the pores forming in the FC, the specimens were left in the water for 1 day. A weight was placed on the FC in order to allow it to sink in water. With this test method, the water absorption ability of all closed-cell pores forming the LFC could be measured. Water absorption test results were found according to the following formula in TS EN 1097-6 [27].

$$\text{Water Absorption } (\%) = \frac{(M1-M2)x100}{M2}$$
(1)

where,

M_1 = Saturated dry surface weight of FC removed from water after 24 hours (g),
M_2 = Initial dry weight of FC (g).

Finally, microscope image analyzes (at 10x, 22x, and 100x magnification) and SEM image analyzes, which are commonly used to view the microstructure of cement-based materials [28], were performed on 28 day age specimens.

3. Experimental Result and Discussion

The results for the compressive strength of the specimens produced in the study are given in Table 5. As can be seen from the Table 5, the lowest compressive strength of the foam concretes produced was obtained on the 1st day and the highest compressive strength was obtained on the 28th day. It was also observed that the 1-day and 28-day compressive strengths of LFC increased by approximately 86% and 41%, respectively, compared to FC.

The thermal conductivity coefficient of the LFC was found to be 0.062 W/mK, as seen in Table 5. The thermal conductivity coeffient of the LFC was approximately 15% better than the FC. In order for a material to be a thermal insulation material, the thermal conductivity coefficient of that material must be less than 0.065 W/mK [29,30]. According to the thermal conductivity coefficients obtained from the specimens, LFC can be used as a thermal insulation material with a thermal conductivity coefficient of 0.062 W/mK. Murat and Şeker [1] emphasized in their study that if foam concrete with a specific mass density below 250 kg/m^3 is produced, the thermal conductivity coefficient of this foam concrete will be below 0.065 W/mK. A similar result was obtained in this study.

Table 5. The results of test for the hardened FC (Sertleşmiş köpük betonun deney sonuçları)

Specimens	Fresh density (kg/m^3)	Hardened density (kg/m^3)	Thermal conductivity coefficient (W/mK)	Compressive Strength (kPa)			
				1 day	3 days	7 days	28 days
FC	290	240	0.073	110	218	365	485
LFC	295	242	0.062	205	384	530	685

Water absorption values of FCs are given in Table 6. After the reference and LFC were kept in water for 24 hours, the water absorption values were measured as 69% and 28%, respectively. The water absorption value of the LFC decreased by about 59% compared to the FC. It is thought that the long chain bonds formed by the latex form a thin membrane by wrapping the entire body of the FC like a net, and this reduces the water absorption value.

Table 6. Water absorption test results of FC (Köpük betonun su emme deney sonuçları)

Specimens	M_1 (gr)	M_2 (gr)	Water Absorption (%)
FC	405	240	69
LFC	310	242	28

Microscope images were taken at 10x, 22x and 100x magnifications for the analysis of the diameter, cell wall and thickness of the pores formed in the FC.

When the image of the FC (Figure 3) at 10 times magnification is examined under the microscope, inhomogeneous closed pores are observed. These pores, which have different diameters, are smaller than 1 micron in some regions and larger than 1 millimeter in some regions (Figure 3). It was determined in the microscope analyzes that the reference FCs produced with the foam additive used in this study formed closed cells in their pores.

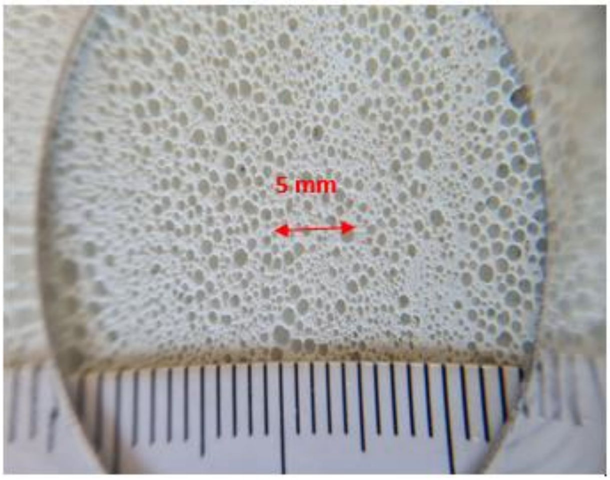

Figure 3. Microscope images belonging to FC (10x magnification)

When the microscope images of the FC were examined at 22 times magnification, most of the closed cell pores formed cells with a diameter of less than 1 mm. In addition, it was observed that the pore diameters formed did not show a homogeneous distribution (Figure 4).

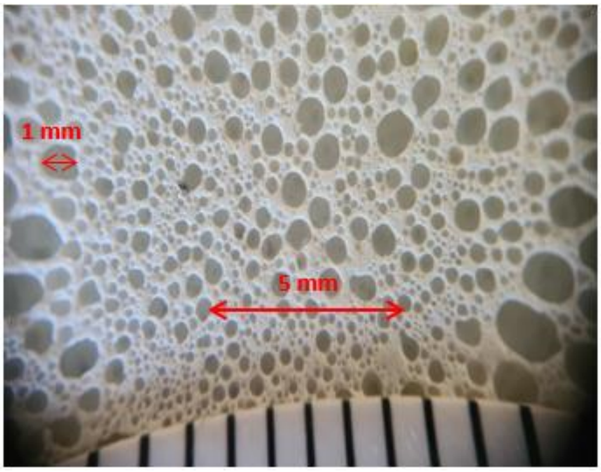

Figure 4. Microscope images belonging to FC (22x magnification)

In Figure 5, it was observed that the closed cell outer walls formed in the FC at 100 x magnification were surrounded by concrete with a thickness of approximately 100 microns. In some pores, the thickness of the outer wall reaches 200 microns. It can be clearly seen at 100 times magnification with a microscope that the pores formed in the FC are completely surrounded by concrete and form closed cells. As a result of its ability to form closed cells, no slump occurred in the FC that was molded fresh.

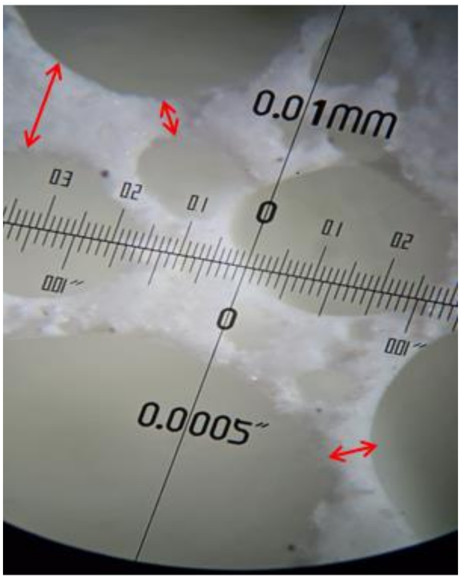

Figure 5. Microscope images belonging to FC (100x magnification)

When the microscope analysis of LFC at 10 times magnification was examined, the pore distribution was more homogeneous compared to the FC (Figure 6). It was observed that all the pores were completely surrounded by concrete.

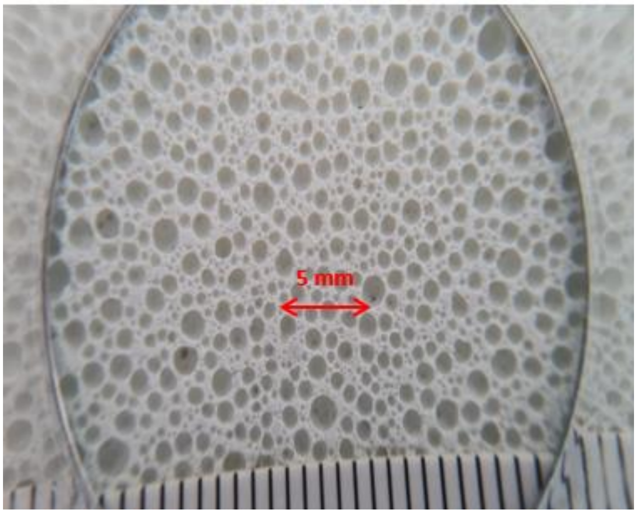

Figure 6. Microscope images belonging to LFC (10x magnification)

When Figure 7 is examined, it is seen that the pore distribution in LFC is more homogeneous than the FC. While cells with a diameter of less than 1 mm form the majority of the pores in the FC, the distribution of cells with a diameter of less than 1 mm and larger in LFC is close to each other.

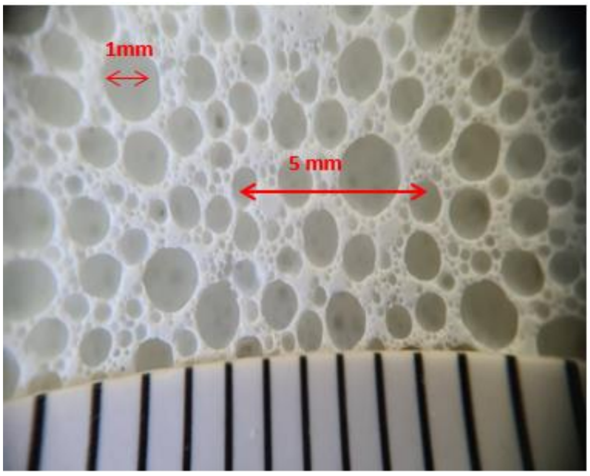

Figure 7. Microscope images belonging to LFC (22x magnification)

It is seen that all the pores formed in the LFC at 100 times magnification are completely enclosed (Figure 8). This indicates the ability of latex to form closed cells. The outer wall thicknesses of the pores that make up the LFC vary between 50 and 100 microns. It was observed that there was a more homogeneous pore distribution compared to the FC (Figure 8).

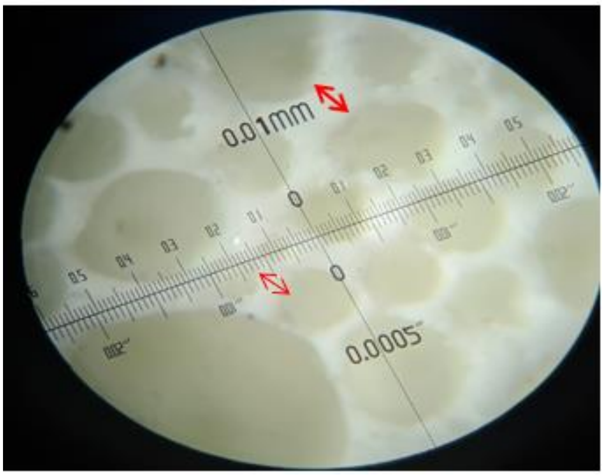

Figure 8. Microscope images belonging to LFC (100x magnification)

SEM analyzes of FC were performed on 28 days. When Figure 9 was examined, it was observed that capillary cracks occurred in the FC. A heat flow bridge was formed from the opening caused by the capillary crack, and as a result, the thermal conductivity coefficient of the FC was adversely affected. It is also thought that this situation has a negative impact on the compressive strength and water absorption value. These capillary cracks could not be detected in eye and microscope analyzes.

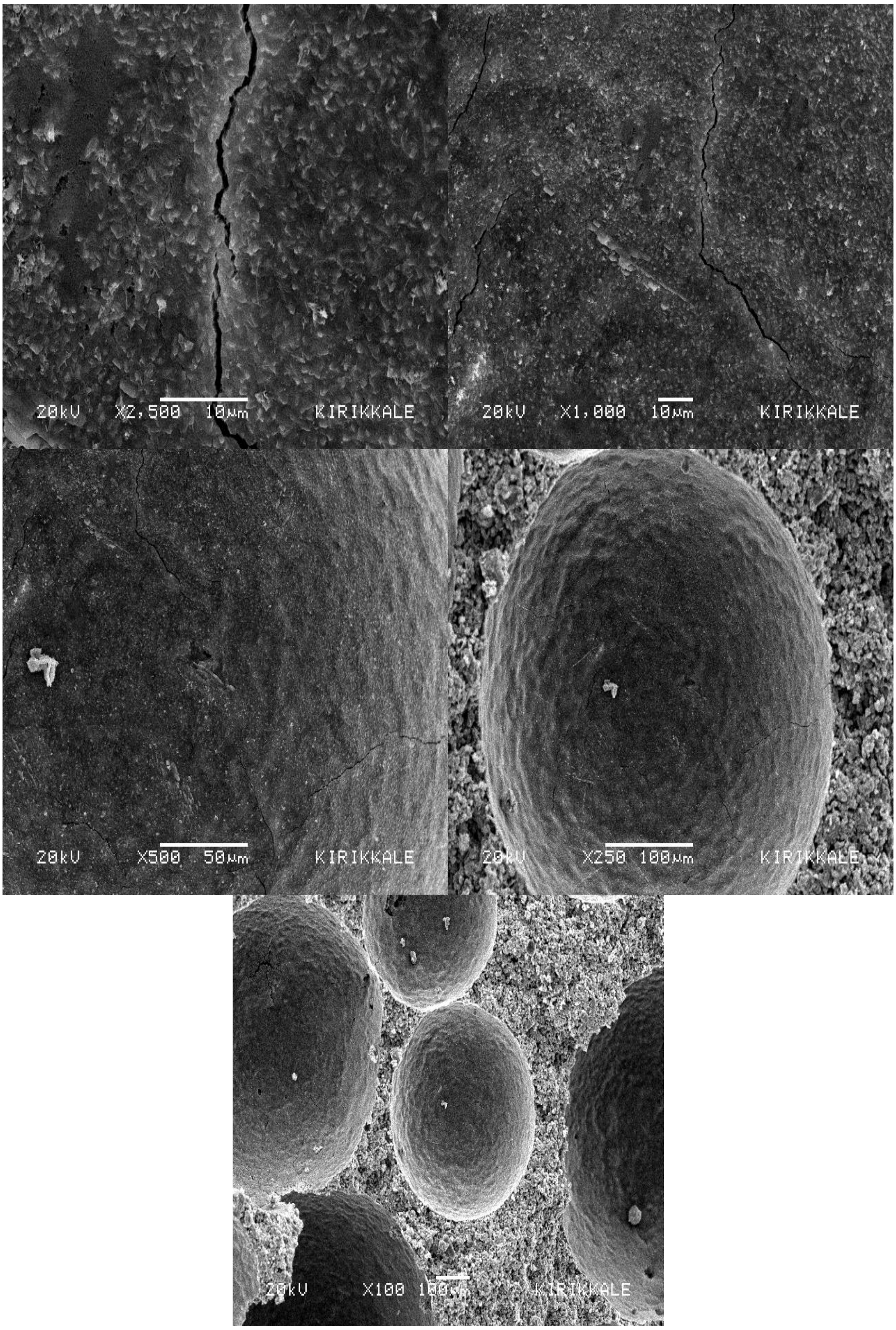

Figure 9. SEM image of FC

When the SEM image analyzes of the LFC were examined, it was seen that there was a chain structure that continues uninterruptedly and envelops it like a net (Figure 10). The long bond structure formed by latex with cement and the formation of a very thin shell enabled the FC to improve its properties. While capillary cracks smaller than 1 micron were detected in the FC, no capillary cracks were found in the latex added FC. It is thought that latex can be used to prevent the formation of capillary cracks in the production of FC. This chain structure formed by latex was clearly seen in SEM analysis at 2500 and 5000 times magnification.

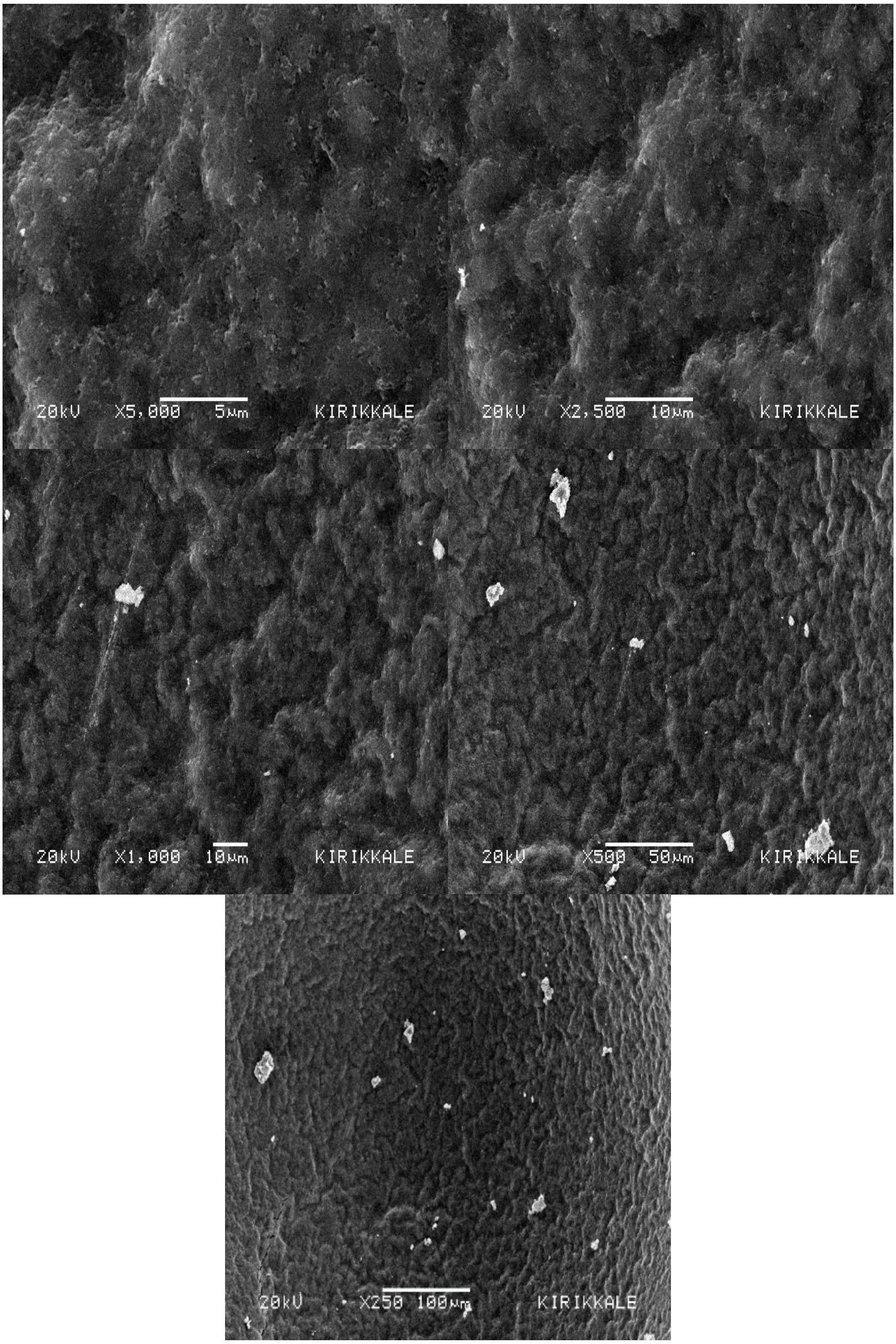

Figure 10. SEM image of LCF

4. Conclusions

In this study, for the first time, long chain bonds formed by latex in concrete were determined by SEM image analysis. Thanks to the long chain bonds made by latex, an impermeable structure has been formed within the FC. As a result of this chain bond formed by latex, the water absorption value of latex added concretes decreased by 59% compared to the FC.

Compared to the FC, the compressive strength of the LFC increased 86% in 1 day and 39% in 28 days.
In SEM analysis, while capillary cracks were detected in the FC, it was determined that a stable structure was formed with long chain bonds and no capillary cracks were formed in the LFC.

The thermal conductivity coefficient of the LFC was found to be 0.062 W/mK. Since this value is less than the thermal conductivity value of 0.065 W/mK [29,30], this FC can be used as a thermal insulation material.

As a result, the use of latex in the production of FC contributed positively to the compressive strength and thermal conductivity. In particular, one of the negative aspects of foam concrete, excessive water absorption, has been significantly reduced by adding liquid latex to the mixture.

In future studies, the effect of latex bonding structure on normal and high strength concretes can be investigated. Especially, the effect of latex on early strength of high-strength concrete can be investigated.

Conflict of Interest Statement

The authors declare that there is no conflict of interest

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