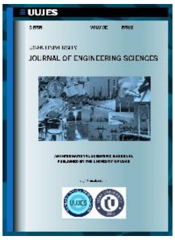

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Research article

EXPERIMENTAL INVESTIGATION OF THE BEHAVIOR OF FIBER REINFORCED CONCRETES

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Abstract

Concrete is a brittle material with low tensile strength and tensile unit strain. Due to these weak characteristics of concrete, there is a need for improvement. In line with this goal, efforts are made to enhance the weak properties of concrete by incorporating fibers with high technical specifications, produced from various materials, into the concrete. In this study, the effect of waste fibers used in mixtures at ratios of 0.5%, 1%, 1.5%, and 2%, while keeping the cement content constant in the produced concrete mixtures, on the physical and mechanical properties of the concrete was investigated. Standard cube specimens were produced for compressive strength testing. As the fiber ratio increases, the thermal conductivity value decreases, and it is believed to have a positive impact on thermal insulation.

Keywords: *Concrete; fibers; waste fibers; fiber-reinforced concrete.*

1. Introduction

Concrete has been the most commonly used building material for many years. The widespread use of concrete has led researchers to further developments in concrete. Concrete is a building material formed by combining gravel and sand with a binder and water. The binding agent is usually cement. Concrete is the most widely used building material today, especially in our country. It is preferred because it is economical, durable and can be used for a long time. It is an indispensable material both in modern design applications and in achieving the desired durability. Today, it is used as the main element

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in various structures such as dams, water structures, tunnels and bridges, especially multi-storey buildings. [1]

The way for concrete structures was paved with the patent of Portland cement by Joseph Aspdin in 1824. In 1801, Francois Coignet published his first article on the weakness of concrete in tensile. The first reinforced concrete structure using concrete and steel was built by Francois Coignet in 1852. The first person to put forward the idea of using concrete and steel together in bending was T. Hyatt from the USA. Hyatt published his studies on reinforced concrete, which he had been continuing since the 1850s, in 1877, and followed the publication of the results of many studies conducted in this field in Europe. [2] Concrete has an important place in the development of human history and in the works of ancient civilizations that still exist today. Lime-based binders were used in the construction of the pyramids, structures such as the Pantheon and the Coliseum were built with bozzolans, and a type of binder called Khorasan mortar was used in Anatolia and Central Asia. The beginning of the modern history of concrete is considered to be Louis Vicat's production of the first artificial cement in the 1800s and Joseph Aspdin's patenting of 'Portland Cement'. With the advent of reinforced concrete building systems, concrete has begun to be used extensively. Concrete, which has a very wide usage area today, has become the most consumed material in the world after water. It is a building material that is very economical, easy to produce and use, reliable and durable in proper use, and does not require service. Materials such as concrete, whose raw material is cement, have a brittle structure with low tensile strength and tensile deformation capacity. Some properties of concrete produced by traditional methods (such as deformation capacity, fatigue strength, tensile strength, abrasion resistance and toughness) are low. By adding fiber to concrete, these weak properties of concrete have been improved and interest in materials such as concrete has increased. [3] Concrete; It is a building material that consists of a homogeneous mixing of cement, water, aggregate and chemical or mineral additives, initially has a plastic consistency, can be shaped, and gains strength by solidifying and hardening over time. [4] Concrete is widely used because it is a building material with high compressive strength and heat resistant. However, traditional concretes cannot provide the desired properties in some cases and cause negative situations to occur. In order to significantly improve and strengthen the weak properties of concrete, its technical properties can be improved by adding different materials into the concrete. In this case, the use of special concrete becomes mandatory. With the advancement of technology, there have been advances in the concrete industry and these innovations in concrete production have entered concrete technology under the name of special concretes. [5] There are many different types of special concretes developed for specific purposes and uses. In general, it is aimed to change and improve some concrete properties and/or to give some new properties to the concrete by changing the Portland cement matrix phase and/or aggregate phase in some way. Although some of these special types of concrete have been used in the construction industry for a long time, some are newly introduced to the concrete industry. [6] An important innovation has occurred as a result of the studies carried out in the field of building materials in recent years. These studies, called fiber concrete technology, are based on the use of fibers with various properties in concrete and cementitious materials. The use of fibers in building materials is not actually a new concept discovered in recent years, and it is known that various organic fibers were used in many historical buildings. However, as a result of developing technology in recent years, high-performance fibers have emerged and the use of these fibers in cementitious composites has become increasingly widespread. [7] Fiber concrete is a composite material with mechanical and physical properties that differ from unreinforced concrete obtained by adding fibers to normal or high strength concrete. One of the most important mechanical properties of fibrous concrete is its energy absorption capacity, also called toughness. Studies on fibrous concrete, which has taken its place in the construction world with its increasing use, has gained intensity. [8] Fibers commonly used in concrete; They are steel, polypropylene, carbon and alkali resistant glass fibers. In fibrous concrete, the most important feature that must be ensured in all fiber types is that the fibers are distributed homogeneously within the concrete and this distribution does not deteriorate after the concrete is mixed. Uniformly distributed fibers prevent cracks in the concrete and slow down the progression of cracks in the concrete, making the concrete more durable. For this reason, fibrous concrete is generally preferred in the floor concrete of large factory constructions, roads and in the production of prefabricated structural elements. [9] Fibers provide important benefits such as filling the voids in the concrete, reducing shrinkage and shrinkage cracks, and increasing the impact resistance of concrete. That's why in recent years, leading concrete companies in our country have increased their fibrous concrete production. [10] Previous studies have examined the mechanical properties of fibrous concrete with different mixtures. The biggest disadvantage of concrete is its low tensile strength. Depending on the place of use and purpose of concrete, different properties are expected from concrete. Special concretes are used for this, fibrous concrete is one of them. [11] In this study, the behavior of fibrous concrete was experimentally examined by using fibers, which are waste fabric pieces, in certain proportions and certain grams in the concrete. In experimental studies, cube samples with dimensions of 100 × 100 × 100 mm were produced and fibers were placed in certain proportions. The fibers placed inside the concrete are given in Fig. 1. It is thought that with these experimental studies, the behavior of fiber-added concrete and the use of waste fibers will progress in a positive direction.

Fig. 1. Waste fabric pieces fibers

2. Materials and Method

In this study, C 30 concrete will be used and the amount of cement is kept constant and fibrous concretes are prepared at 0.5%, 1%, 1.5% and 2% of the cement weight. 10 cube samples from each series with dimensions of 10 × 10 × 10 cm were produced. In the series produced, the mixture was made by mixing fibers with fiber weights of 15 g, 30 g, 45 g, 60 g, and 0.5%, 1%, 1.5% and 2% of the cement weight. In addition, witness samples were produced from fiber-free C 30 concrete. The physical and mechanical properties of the cement used are given in Table 1, and the mixing ratios of the produced samples are given in Table 2.

Table 1. Mechanical and physical properties of cement [12]

Composition	**CEM I 42,5 R (%)**
Density (gr/cm^3)	3,11
Initial setting time (min.)	169
Final setting time (min.)	255
Volume expansion (mm)	0,77
2-days compressive strength (MPa)	34
28-days compressive strength (Mpa)	55,4

Table 2. Chemical properties of normal aggregate and cement [12]

Composition	**CEM I 42,5 R (%)**	**Normal Aggregate (%)**
SiO2	19,1	20,9
Fe2O3	2,65	0,2
Al2O3	5,19	0,4
CaO	63,40	42,8
MgO	1,83	0,4
SO3	2,95	-
TiO2	-	<0,1
Na2O	0,22	<0,1
K2O	0,94	0,1
Cl-	0,011	-
P2O5	-	<0,1
MnO	-	<0,1
Residue insoluble in HCL	0,32	-
Free lime	-	-
Alkaline equivalent	0,84	-
Total addition	-	-

Experiments for the production of concrete samples and determination of their physical mechanical properties were carried out in the Building Laboratory of Uşak University, Faculty of Engineering, Department of Civil Engineering. For the thermal conductivity coefficient experiment, the test was carried out in the Mechanical Laboratory of Ege University Mechanical Engineering. In this study, a total fibrous sample and a normal concrete sample were produced for comparison. The mixing ratios of the produced samples are given in Table 3. The samples were produced in the form of cubes. Cube samples were filled into cubes of 100 × 100 × 100 mm in size, first the cubes were oiled and then placed on the shaking table, and the concrete mixture mortar was filled in 3 stages by shaking with the shaking table for 10 seconds at each stage. The wrapping process is done to ensure that there are no gaps in the concrete and that it is distributed and settled homogeneously. For cube samples, 10 pieces were produced for each series. All samples were kept in a sheltered area for 24 hours and removed from the molds properly with the help of rubber wedges. The samples were kept in a 20±2 °C curing pool until the day of the experiment. Lubricating the molds, removing the samples and placing them in the curing pool are given in Fig. 2.

Fig. 2 Lubricating the molds, removing the samples and placing them in the curing pool

Table 3. Produced samples

Code	Weight of fiber	Cement	Fiber
	(gr)	Weight (%)	Rates (%)
NB	-	100	-
NL-0,5	15	99,5	0,5
NL-1	30	99	1
NL-1,5	45	98,5	1,5
NL-2	60	98	2

3. Experiments and Results

In this study, ultrasound measurement experiment, water absorption experiment, uniaxial pressure experiment, SEM analysis experiment and thermal conductivity coefficient experiment were carried out. To measure ultrasound transmission velocities, the Ultrasound measuring device (Fig. 3) in the Building Laboratory of Uşak University, Faculty of Engineering, Department of Civil Engineering was used. Ultrasound experiment was carried out in accordance with TS EN 12504-4 [13] standard, Ultrasound velocity measurement was made with a digital display Ultrasound measurement device powered by a 12 volt accumulator. The instrument was first set to zero and then calibrated. By applying grease to both sides of the samples, gaps were prevented between the probes and the sample. In this experiment, a total of 8 fibrous cube samples of 10 × 10 × 10 cm dimensions, 2 from each series, and 2 blank samples were used. With the experiment performed on cube samples, the transmission times of sound waves were measured. In evaluating the ultrasound speed test results, the Ultrasound speed transition time values, which are read as microseconds (µsec), were calculated with Equation 1 and the Ultrasound speed was calculated in km/s. Ultrasound velocity measurement results of fibrous concretes are given in Fig. 4.

$$V=L/t \quad (1)$$

V: Ultrasonic velocity (km/s),
L: Sample size (km),
t: Ultrasonic pulse time (sn),

Fig. 3 Ultrasound measurement experiment

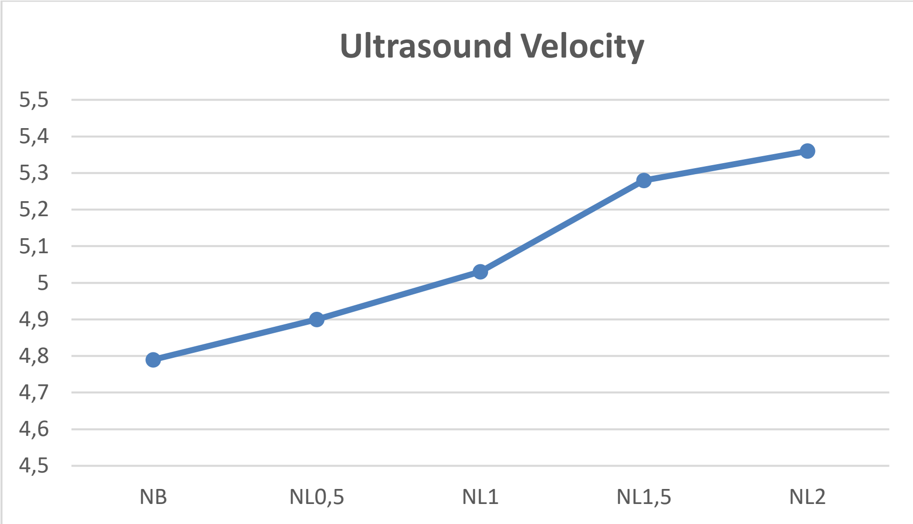

Fig. 4 Ultrasound velocity test results of fibrous concretes

A total of 12 samples, three from each series, of 10×10×10 cm cube samples kept in the curing pool, and 3 cube witness samples were removed from the water and their wet unit volume weights were measured with a precision balance. After 24 hours, the dry unit volume weights of the dried samples were measured again with the same precision balance and the following values were obtained. The water absorption value by weight was calculated by calculating the difference between the saturated weight of the samples taken out of water and the weight of the dried samples. Water absorption capacity is found by dividing the amount of water entering the concrete by the dry weight of the concrete and can be expressed as a percentage. Wet and dry unit volume weight measurement results of fibrous concrete are given in Fig. 5. The water absorption test was carried out in accordance with TS 699 [14].

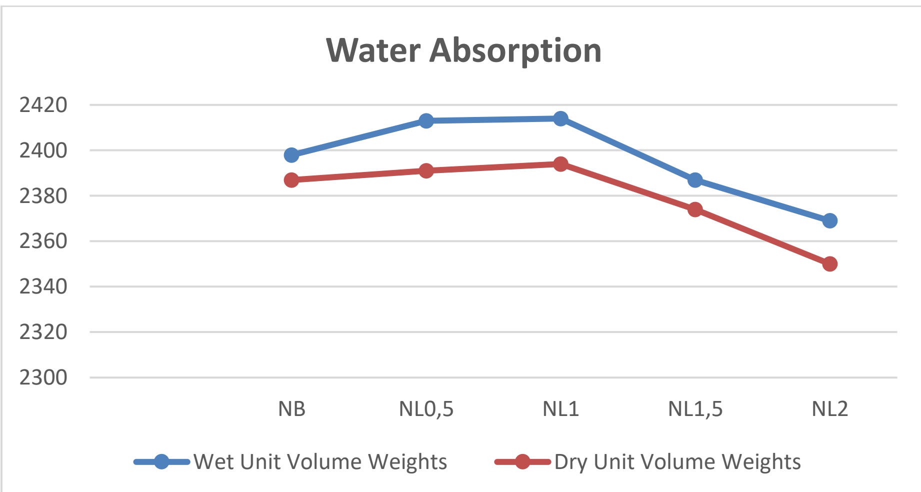

Fig. 5 Water absorption test results of fibrous concretes

In the destructive testing method, uniaxial compression tests were performed for cube samples. The uniaxial pressure test and the test instrument used in the experiments were made in accordance with TS EN 12390-4 [15]. For the uniaxial pressure experiment, a 300-ton capacity uniaxial pressure press (Fig. 6) located in Uşak University Building Materials Laboratory was used. In the pressure experiments, the loading rate was kept constant at 0.35 MPa per second. In this experiment, a total of 12 10 × 10 × 10 cm fibrous cube samples and 3 blank samples were tested. For this purpose, the previously prepared cube concrete samples were broken on the 7th and 28th days, and the compressive strength values of the concrete sample were calculated by substituting the load value at the time of breaking into Equation 2. The 7th and 28th day compressive strength measurement results of fibrous concrete are given in Fig. 7.

$\sigma = P/A$ (2)
σ: Compressive strength (MPa)
P: Breaking strength (N)
A: Cross sectional area in the load direction (mm2)

Fig. 6 Compressive strength test device

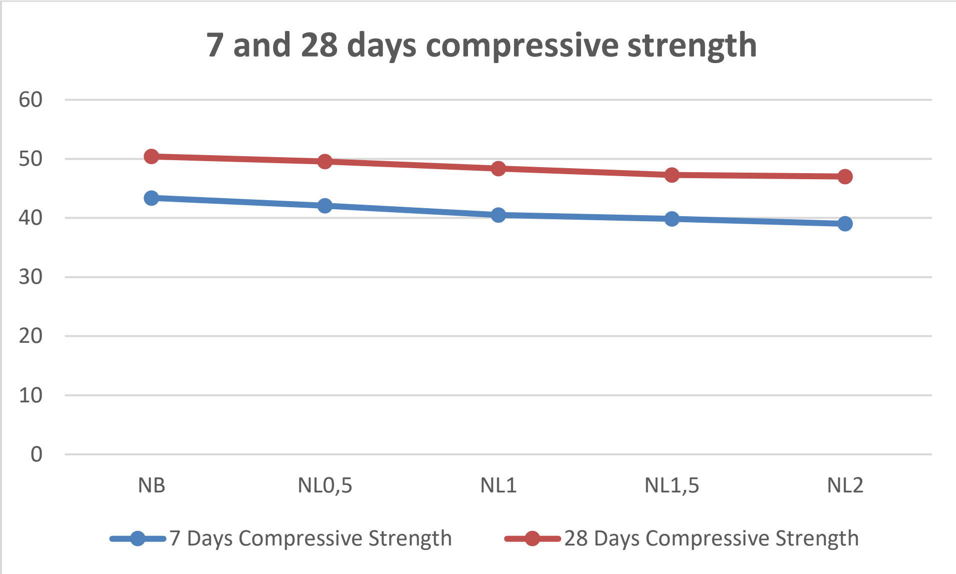

Fig. 7 7th and 28th day compressive strength measurement results of fibrous concrete

In the SEM analysis experiment, microstructure examination was carried out by taking electron microscope images of the samples taken from the fracture surface of the samples. Microscale evaluations were made about the mechanical behavior of the fibers by imaging the surface properties of the fibers after breaking and the post-experiment states of the microstructure at the junction with the matrix. SEM analysis results are given in the figures below. Images of fiber-free concrete samples in SEM analysis are given in Fig. 8. SEM analysis images of waste fabric samples with 0.5% fiber content are given in Fig. 9. SEM analysis images of waste fabric samples with 1% fiber content are given in Fig. 10. SEM analysis images of waste fabric samples with 1.5% fiber content are given in Fig. 11. SEM analysis images of waste fabric samples with 2.0% fiber content are given in Fig. 12.

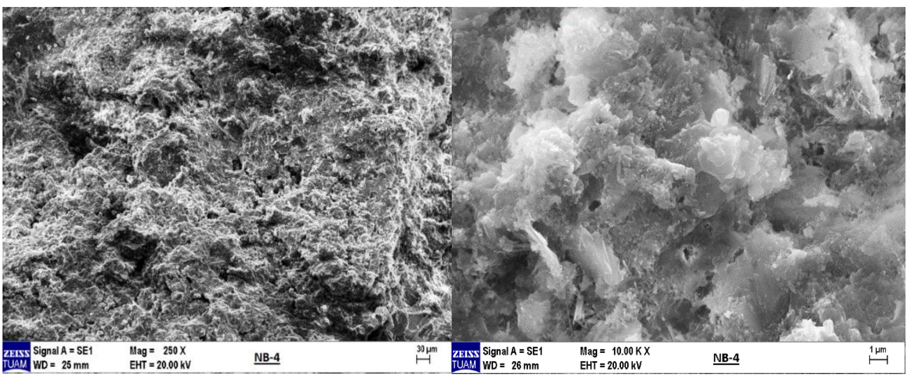

Fig. 8 Images of fiber-free concrete samples in SEM analysis

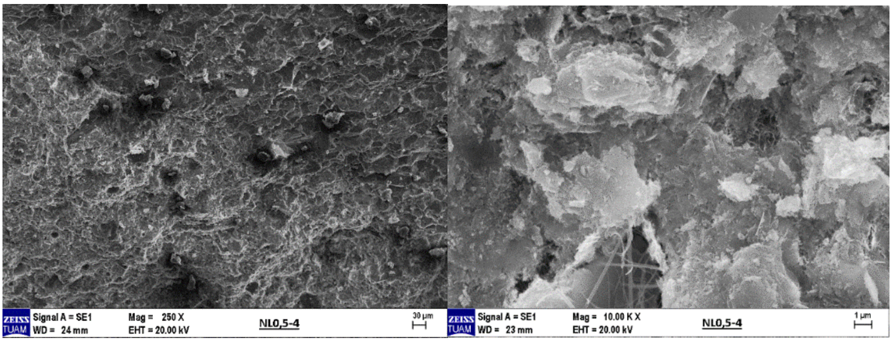

Fig. 9 SEM analysis images of waste fabric samples with 0.5% fiber content

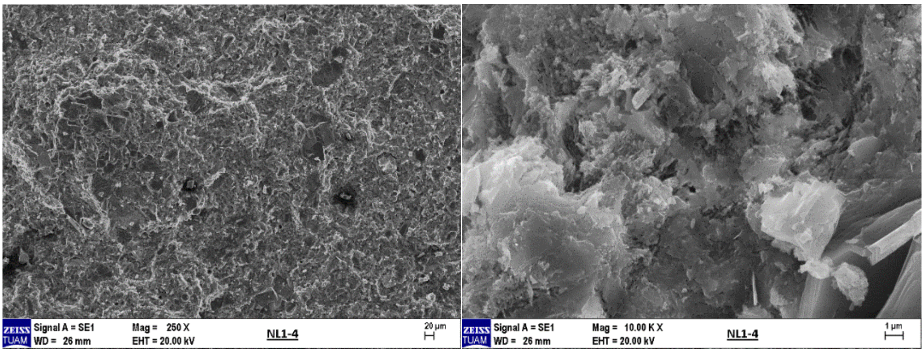

Fig. 10 SEM analysis images of waste fabric samples with 1% fiber content

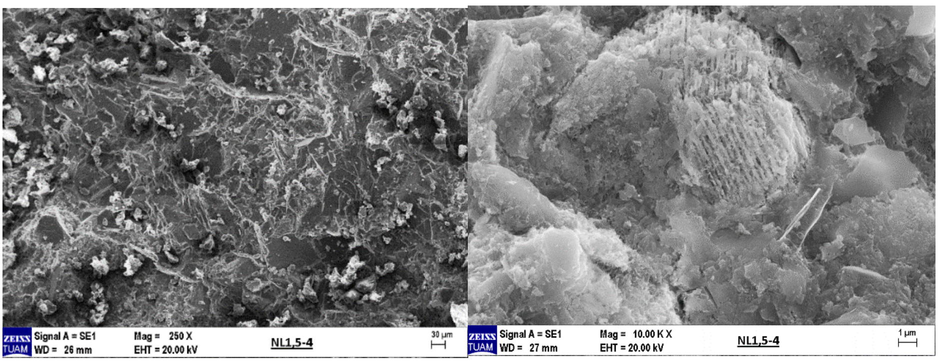

Fig. 11 SEM analysis images of waste fabric samples with 1.5% fiber content

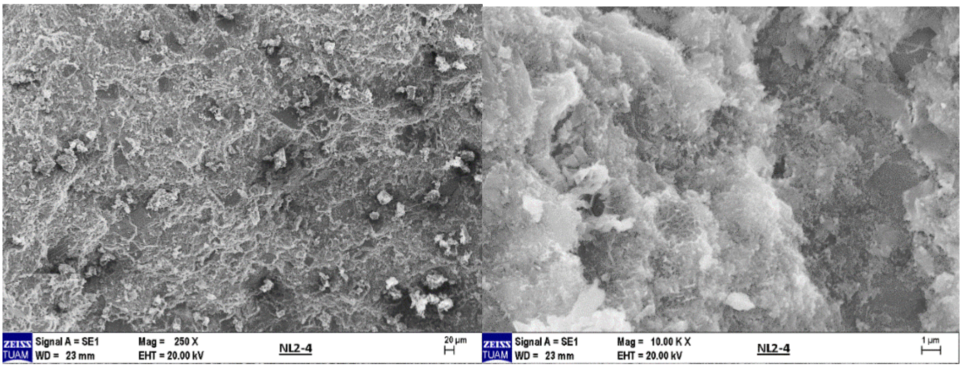

Fig. 12 SEM analysis images of waste fabric samples with 2.0% fiber content

To determine the thermal conductivity coefficient of concrete samples, experiments were carried out in the Mechanical Engineering Laboratory of Ege University Faculty of Engineering. Samples with dimensions of 10 x 10 x 10 cm were cut and turned into samples with dimensions of 10 x 5 x 2 cm. One fibrous sample from each series was cut and experiments were carried out on 4 fibrous samples and 1 blank sample. The conductivity test device for the thermal conductivity test is given in Fig. 13. QTM-500 device was used in this experiment and the test device has ASTM 1113-90 [16] standard. The thermal conductivity of a homogeneous material is the amount of heat passing perpendicularly in unit time, unit area and unit thickness, under equilibrium conditions where the difference between two surface temperatures is 1 °C. Thermal conductivity of the structure and various thermal insulation materials is measured by two methods. These are steady state and transition state. Generally, the heated plate method is used in the steady-state method. With this method, the average thermal conductivity of the plate-shaped examination sample placed symmetrically on both sides of a heated plate is found. Meters can detect the thermal conductivity of smaller materials in less time during passage. [17] The thermal conductivity coefficient measurement results of fibrous concrete are given in Fig. 14.

Fig. 13 Thermal conductivity tester

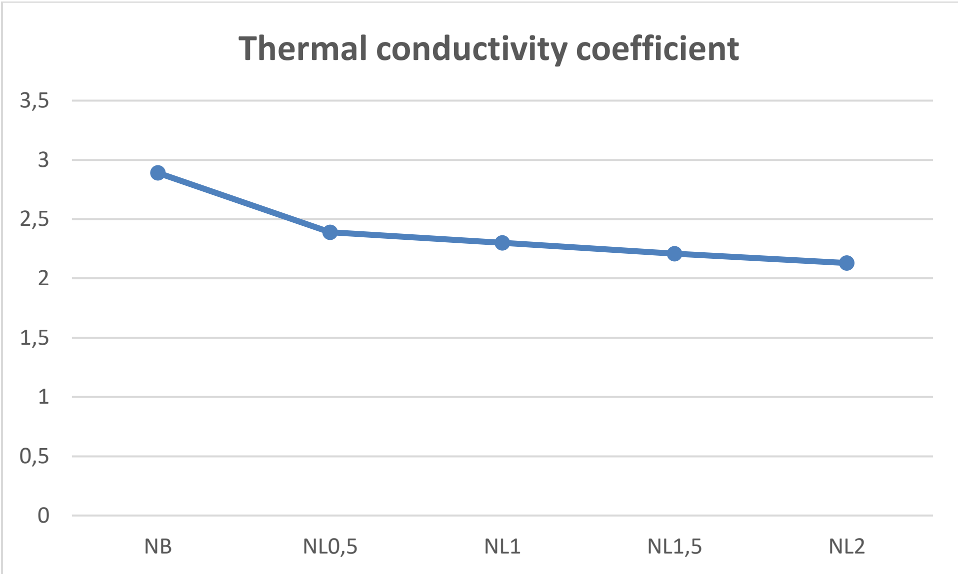

Fig. 14 Thermal conductivity coefficient measurement results

As a general result of these experiments, the use of fibrous concrete does not cause any negative technical situation in the concrete and provides many benefits to the concrete. In the results of 28-day compressive strength tests, increasing fiber contribution caused a decrease in compressive strength. However, this decrease remains within the standards. All fibers gave positive results in compressive strength and there is no significant difference between the fibers. As the fiber contribution increased, the water absorption rate and ultrasound transmission rates increased, while the thermal conductivity coefficient decreased. In the images in the SEM analysis, it was understood that the differences between the mechanical properties of fiber concrete were clearly evident in the micro-scale examinations. Since the increase in fiber ratio reduces the thermal conductivity value in all fiber concretes, it is thought that this will contribute to thermal insulation.

4. Conclusion

The use of fiber additives in concrete provides many technical advantages. Different usage rates bring different features and different costs. Although the workability of fiber-added concrete is low, the mechanical properties of fiber-added concrete become more important, especially under difficult conditions**.** As the fiber dosage increases, water absorption rate and thermal conductivity coefficient decreases. It is thought that the increase of fiber dosage will contribute to thermal insulation by decreasing the thermal conductivity value. Fiber-added concretes can be used especially in concretes with high surface areas such as airports and road concretes, which can improve plastic shrinkage cracks. As a result, when fiber-added concrete is used instead of normal concrete, it does not affect the compressive strength and thermal insulation, but it reduces its weight and thermal conductivity coefficient. Concretes containing fiber can be used in insulation concrete applications in cold climate regions due to their low thermal conductivity coefficient. It can be said that the use of fiber added concretes can be used especially in concretes with high surface area such as airfields and road concretes, which can provide improvement in plastic shrinkage cracks.

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