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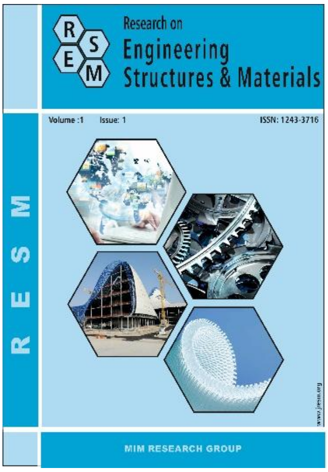

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Research Article

Effect of polypropylene fiber addition on thermal and mechanical properties of concrete

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Abstract

The concrete is a brittle material which has low tensile strength and tensile strain capacity. These weak points of concrete can be fixed by using fibers made of different materials with high technical specifications in concrete. In this study, it is aimed to investigate the physical and mechanical properties of concretes obtained by using polypropylene fibers at different ratios by keeping amount of cement constant in the concrete mixtures. 100x100x100 mm cube specimens for compressive strength, 100x100x500 mm beam specimens for tensile strength in bending tests were produced. Also, 100x100x100 mm cube specimens for thermal conductivity tests were produced and these samples were tested by cutting to 80x40x10 mm. It was observed that as the rates of fibers were increased, ultrasonic velocity, water absorption and flexural strength were increased but slump, thermal conductivity coefficient and compressive strength were decreased.

1. Introduction

Since the existence of humankind, the second basic necessity has been the sheltering after the necessity of eating and drinking, In this way the building sector has always remained on the agenda and has continued to work on developing practical methods. In today's world, as in all areas, the basic goal is to reach the solution at the earliest with minimal expenditure. Various special properties have been developed or some special concrete with different production and application techniques are widely used due to emerging needs in today's use. It is very important to design and economical production of concrete for the purpose of use [1]. Due to the increase in the world population, complex and multi-storey buildings have been widespread in recent years instead of simple and single storey buildings. As the building height and number of floors increase, the quality of the material used becomes important [2]. In multi-storey buildings, concrete performance is of great importance in order to reduce the structural safety and the effect of the earthquake [3].

Concrete; is a composite material consisting of mortar phase and aggregate which is obtained by mixing cement, water, aggregate and additives if necessary (mineral, chemical, fiber etc.) in certain conditions and ratios. Concrete is in plastic form at the beginning and gains resistance by hardening due to chemical reaction (hydration) over time between cement and water [4]. When concrete has just been mixed, it takes the name of fresh

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concrete and when it hardens it becomes hardened concrete [5]. When the materials which form the composition in concrete, are specifically rated, the mixture can be poured anyplace and brings a plastic mass that can take the shape of the mold [6].

The concrete is a brittle material which has low tensile strength and tensile strain capacity. Conventional concrete is typically shows poor performance in terms of fatigue strength, cavitation, abrasion resistance, tensile strength, deformation capacity, shear strength, load carrying strength after cracking and toughness. Where these properties of concrete are obviously required, the addition of high-tech fibers produced from different materials within the concrete improves the above weaknesses of the concrete. Thus, polypropylene fiber, carbon fiber, plastic-glass based fibers and steel fibers have begun to be used in concrete. In terms of advantages in the field of Civil Engineering, the importance of fiber reinforced concrete is increasing rapidly and important steps have been taken to improve the properties of composites [7].

Fig. 1 Polypropylene Fiber

The polypropylene fiber used in this study is a very light polymer that is grouped within the thermoplastics as material type. It forms almost half of the raw materials used in daily life such as clothes hangers, kitchen and bathroom utensils, buttons, electrical materials, cables, yarns, laboratory utensils, stretch films, automotive Industry, etc. From this point of view, it is also possible to say that polypropylene fiber is a cheap plastic to manufacture. The most important effect of polypropylene fiber in concrete or plaster is to control cracks due to plastic shrinkage within the first few hours after pouring concrete into the mold. In the first phase of concrete hardening, the rate of formation of concrete strength is slower than the rate of formation of tensile stresses due to shrinkage. This plastic shrinkage is essentially a natural consequence of evaporation and chemical reaction starting between water and cement [8]. Polypropylene fibers are not very effective in increasing the mechanical strength of concrete compared to steel fibers. Nevertheless, they give energy absorbing capability to concrete at minimum levels and they are very effective in plastic shrinkage. Polypropylene fibers are particularly preferred against non-strong shrinkage. The function of polypropylene fibers is limited with the soft, plastic phase of concrete, the strength-enhancing effect of the steel fibers also persists significantly after the concrete setting and hardening. Steel fibers also have a crack-proof and limiting effect in the plastic phase of concrete. However, it is weaker than the effect of polypropylene fibers dispersed perfectly in concrete (Fig. 1). In addition, steel fibers give the material a certain strength and toughness, which significantly increases the strength of the concrete and reduces the cracks that will occur in hardened concrete due to their long-term drying shrinkage [9].

If we look at the literature studies using polypropylene fiber in concrete;

According to Acıkgenc et al [10] polypropylene fibers were added into concrete by the rate of 1% and 2% by volume and concrete samples were produced. When the fiber ratio is 1% in concrete, the compressive strength of the concrete is increased, and the compressive strength of concrete is decreased when it is 2%.In addition, as the water/cement ratio decreased, the compressive strength increased and the flexural strength increased as the fiber ratio increased. Likewise, capillary water absorption and abrasion resistance properties of concrete were also positively affected by polypropylene fibers. As the properties of fresh concrete and concrete mixture proportions were changed, polypropylene fibers had different influence on strength and durability. According to Sumer and Saribiyik [11] polypropylene fiber and silica fume were added into concrete by the rate of 0.1%, 0.5% and 1% by volume and concrete samples were produced. It was observed that as the fiber ratio increased, compressive and flexural strength increased. Likewise, it has been determined that polypropylene fiber has a positive effect on the abrasion resistance and capillary water absorption properties of the concrete and it would be appropriate to use it in field concrete. According to Salahaldein and Muhsen [12] concrete cube samples of 150 mm x 150 mm x 150 mm dimensions were produced by using rate of 1%, 1.5% and 2% polypropylene fiber in concrete. The compressive strengths of concrete samples were investigated and the percentage increase of compressive strength of polypropylene fiber concrete mixes compared to the mix without fiber is observed from 4 to 12%. According to Topcu et al [13] polymer based polypropylene fibers were added to mortar mixtures in ratio of 0.6% 0.8% 0.9% and 1.1% by volume. On the mortars, compressive strength, flexural strength, ultrasonic velocity, water absorption and dynamic modulus of elasticity were defined and compared with control samples. According to experimental results, it was seen that when the compressive strength and dynamic modulus of elasticity was decreased by addition of fibers to mortar, flexural strength and water absorption was slightly increased. According to Sohaib et al [14] concrete samples were produced using polypropylene fiber instead of cement at 0.5%, 1.5%, 2.5%, 3.5% and 4.5%. The compressive and tensile strengths of concrete samples were investigated. It was seen that the compressive strengths increased by 11% compared to the control samples and the tensile strengths increased by 17% compared to the control samples as 1.5% of cement contents; however, after 1.5%, the compressive and tensile strengths decreased.

As known, various fiber added materials are used to make the concrete more durable and more impermeable. One of them is polypropylene fiber. Also, the tensile strength of concrete is weak, various fibers are used to increase tensile strength. In this study; investigation of the effects of polypropylene fiber on the compressive and flexural strength of concrete and the effectiveness of polypropylene fibers in preventing the cracking of concrete due to tensile stresses on the surface in concretes with high surface area, such as airfield and road concretes.

2. Material and Methods

2.1. Material

In this study, 15 cement samples were produced at 10 cm x 10 cm x 10 cm sizes using 1%, 2% and 3% (polypropylene fiber) of cement weight, keeping amount of cement constant for C 30 concrete. The chemical properties of cement, normal aggregate and polypropylene fiber used are shown in Table 1 and the chemical and physical properties of the polypropylene fiber are shown in Table 2.

Table 1 Chemical Properties of Cement, Aggregate and Polypropylene Fiber Used in Concrete Mixtures

Composition	CEM I 42.5 R (%)	Normal Aggregate (%)	Polypropylene Fiber (%)
SiO2	20.02	2.75	0.38
Fe2O3	3.52	1.29	0.06
Al2O3	5.16	-	-
CaO	63.46	0.2	53.85
MgO	1.03	2.8	0.34
SO3	2.74	-	-
Loss of ignition	2.35	-	-

Table 2 Chemical and physical properties of polypropylene fiber

Appearance	Natural White Fibers
Purity	% 100 Pure
Specific Gravity	0.91 g/cm^3
Module of Elasticity	3000-3500 N/mm^2 (MPa)
Tensile Strength	450/700 N/mm^2 (MPa)
Melting Point	162 °C
Ignition Point	593 °C
Length	6mm - 12 mm – 19 mm
Profile &Diameter	Circular 18µm - 40 µm

2.2 Methods

Production of concrete samples, physical and mechanical properties tests were carried out in the Construction Laboratory of Civil Engineering Department of Uşak University and Mechanical Engineering Laboratory of Faculty of Engineering of Ege University. In this study, concrete was produced in 4 different mixing ratios. The amount of cement and fiber dosage was kept constant in all mixtures. Mixing ratios of the produced samples are shown in Table 3. Natural spring water was used for mixing water. The concrete mixing process was carried out with the help of a vertical axis mixer. In order to determine the consistency of the samples, slump was measured with Abrams cone. For use in various experiments, the mortar was placed in three stages, 100 mm × 100 mm × 100 mm size cube molds on vibratory table unit. At each stage, the mortar was vibrated by the vibratory table tool for 10 seconds. For each series, 15 cube samples were produced. The samples were left in mold for 24 hours. At the end of this period, the samples were removed from the mold with the aid of rubber wedges. The samples were kept in the curing pool until the day of the experiment.

Table 3 Mixture ratios of the produced samples

Mix	Cement (% wt)	Polypropylene Fiber (%)
NB	100	-
NL1	99	1
NL2	98	2
NL3	97	3

TS EN 12350-2 (2002) standard has been adopted in many countries. In this experiment also called Abrams Cone; as shown in Fig. 2, the top of a 100 mm diameter, 200 mm lower diameter and 300 mm height is cut into three equal layers into a truncated conical metal mold and each layer is freshly squeezed 25 times with a special rod (diameter 16 mm, length 600 mm) concrete filled. Then the filled concrete was pulled up through the truncated cone mold before it was vibrated. The concrete has collapsed with its own weight and the slump value was measured [15].

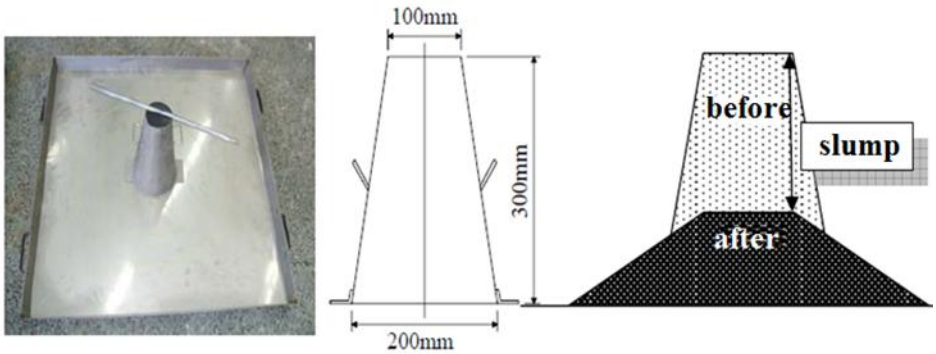

Fig 2. Tools used in the slump test and experimental procedure [7]

In the destructive test method, uniaxial pressure test and flexure test were performed. To measure ultrasonic pulse velocity, ultrasonic measuring instrument in the Construction Laboratory of Civil Engineering Department of Usak University was used (Fig. 3). The ultrasonic velocity measurement was performed with a 12-volt accumulator-equipped with a digital indicator ultrasonic measuring instrument. By spraying grease on both sides of the samples, gaps between the probes and the sample were prevented. By the experiment on the cube samples, transition time of sound waves were measured.

In evaluating ultrasound velocity test results, the ultrasonic pulse velocity time values (microsecond) were calculated in terms of km/s in ultrasonic velocity, formulated by Eq. (1);

$$V = \frac{L}{t} \tag{1}$$

where V is the ultrasonic velocity (km/s), L is sample size (km), and t is ultrasonic pulse time (s).

Fig. 3 Ultrasonic measuring instrument

In order to determine the thermal conductivity coefficient of the concrete specimens that are produced, the experiments were carried out on 80 x 40 x 10 mm samples at Mechanical Engineering Laboratory of Faculty of Engineering of Ege University (Fig. 4). When the difference between the two surface temperatures is 1 ° C under the conditions that have reached equilibrium, the amount of heat passing through "unit time, unit area and unit thickness in perpendicular direction" is the thermal conductivity of a homogeneous material. The measurement of the thermal conductivity of the structure and various thermal insulation materials are done by two methods, in steady state and transition state. The usual method is the heated plate method in steady state. The average thermal conductivity of the plate-shaped examination specimen, which is placed symmetrically on both sides of a heated plate, is found by this method. Measuring devices can detect the thermal conductivity of smaller materials in a shorter time during the transition [16].

Fig. 4 Thermal conductivity measuring device

Three-point flexural test was performed in the destructive test method. For this experiment, the flexural device with 25 tons capacity was used in the Construction Laboratory of Civil Engineering Department of Usak University (Fig. 5). For this purpose, 3 of the previously prepared concrete samples were broken on the 7th day of the concrete casting and 5 of them were broken on the 28th day, and the readings at the time of breaking were used in the Eq. (2) [17]

$$f_{cf} = \frac{FL}{d_1 d_2^2} \tag{2}$$

where f_{cf} is the flexural strength (MPa), F is the maximum Load (N), L is the structural bearing effective span (mm), and d_1 and d_2 are the cross-sectional lengths of the sample (mm).

Fig. 5 Three-point flexural test

3. Result and Discussion

The results of the experiments on the concrete samples produced within the scope of this study are represented in Table 4-5. The results of the polypropylene fiber added concretes are shown in Figs. 6-12.

Table 4 Physical properties of polypropylene fiber added concrete samples

Mix	Dry Unit Weight (kg/m³)	Water Absorption (%)	Slump (mm)	Ultrasonic Velocity (km/s)	Thermal Conductivity Coefficient (W/mK)
NB	2.419	1.80	170	19.50	2.96
NL1	2.395	1.82	45	20.10	2.66
NL2	2.375	1.85	30	20.70	2.40
NL3	2.365	1.95	20	21.10	2.23

Table 5 Mechanical properties of polypropylene fiber added concrete samples

Mix	7 Days Compressive Strength (MPa)	28 Days Compressive Strength (MPa)	7 Days Flexural Strength (MPa)	28 Days Flexural Strength (MPa)
NB	40.70	49.76	7.95	9.68
NL1	38.50	45.88	7.12	9.78
NL2	38.38	45.17	7.30	10.15
NL3	38.12	44.19	7.52	10.45

3.1 Water Absorption Test Results

Based on standard TS EN 1097-6 the values obtained from the water absorption test results are given in the Fig. 6.

Fig. 6 shows that as the fiber dosage increases, the water absorption increases too. Notice that NL3 has the highest value but NB has the lowest value.

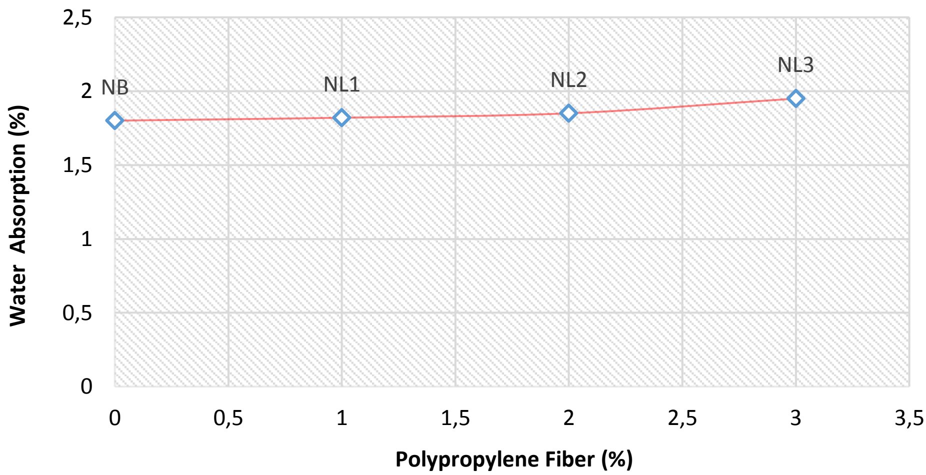

Fig. 6 Water absorption test results of polypropylene fiber added concrete samples (%)

3.2 Slump Test Results

Based on standard TS EN 12350-2 the values obtained from the slump test results are shown in the Fig. 7. This figure shows that as the fiber dosage increases, the slump decreases. Notice that NB has the highest value but NL3 has the lowest value.

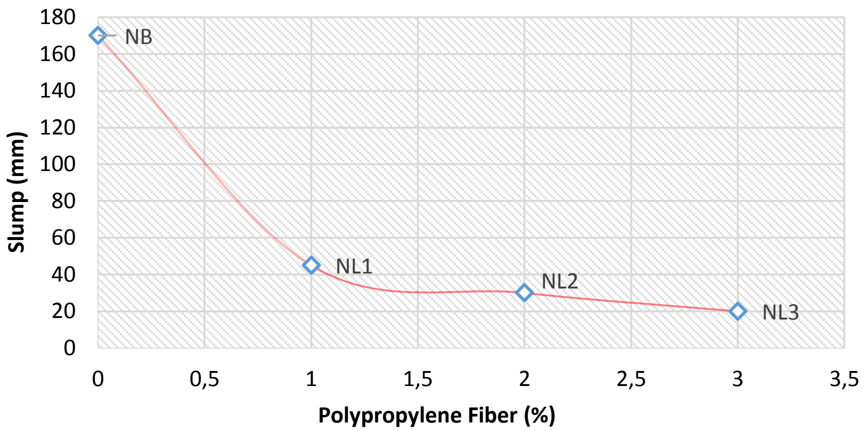

Fig. 7 Slump test results of polypropylene fiber added concrete samples (mm)

3.3 Ultrasonic Velocity Test Results

Based on standard TS 825 the values obtained from the ultrasonic velocity test results are represented in the Fig. 8. The results depicted at Fig. 8 show that as the fiber dosage increases,

the ultrasonic velocity increases. Notice that NL3 has the highest value but NB has the lowest value.

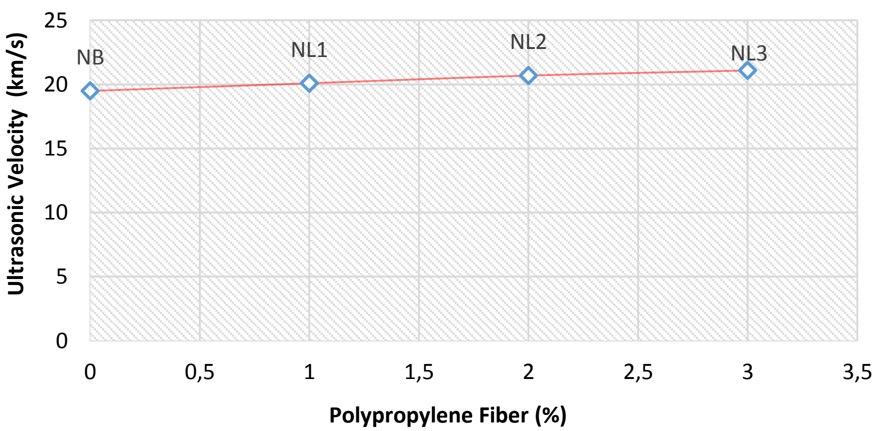

Fig. 8 Ultrasonic velocity test results of polypropylene fiber added concrete samples (km/s)

3.4 Compressive Strength Test Results

Based on standard TS EN 12390-4 the values obtained from the compressive strength test results are plotted in the Fig 9.

Fig. 9 shows that as the fiber dosage increases, the compressive strength decreases. Both 7 and 28 days, the highest value is NB, while the lowest value is NL3.

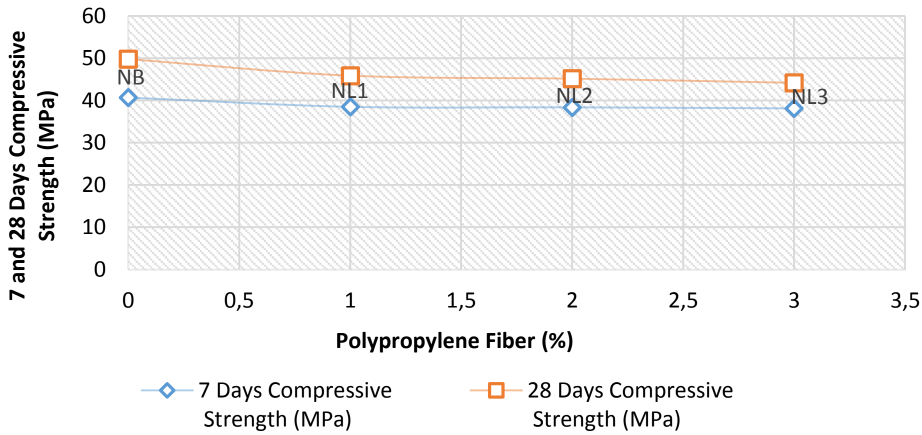

Fig. 9 7 and 28 days compressive strength test results of polypropylene fiber added concrete (MPa)

3.5 Flexural Strength Test Results

Based on standard TS EN 12390-4 the values obtained from the flexural strength test results are depicted in the Fig. 10.

Fig. 10 shows that as the fiber dosage increases, the flexural strength increases for 28 days, while it decreases for 7 days. For 7 days, the highest value is NB, while the lowest value is NL1. For 28 days, the highest value is NL3, while the lowest value is NB.

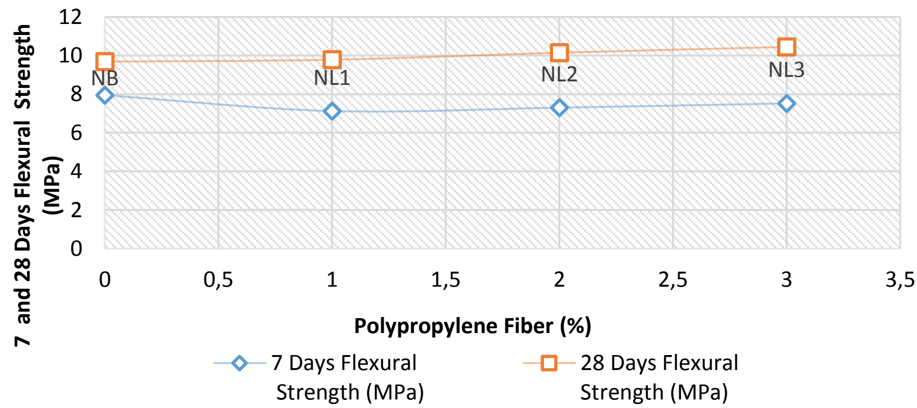

Fig. 10 7 and 28 days flexural strength test results of polypropylene fiber added concrete (MPa)

3.6 Thermal Conductivity Coefficient Test Results

Based on standard TS 825 the values obtained from the thermal conductivity coefficient test results are represented in the Fig. 11.

Fig. 11 shows that as the fiber dosage increases, thermal conductivity coefficient decreases. Notice that NB has the highest value, and NL3 has the lowest value.

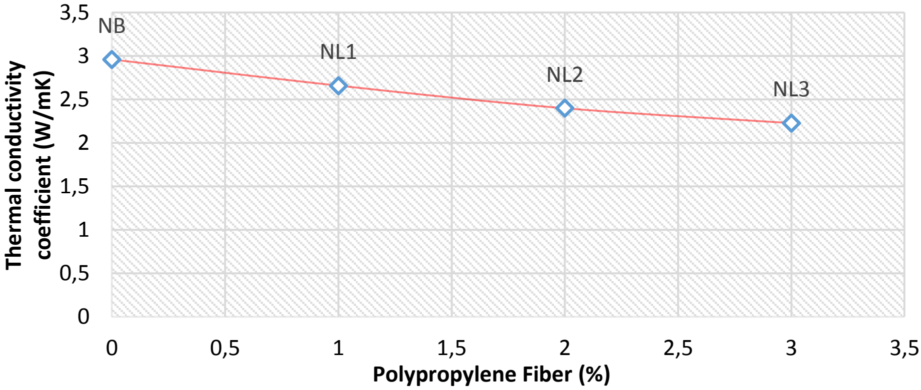

Fig. 11 Thermal conductivity coefficient test results of polypropylene fiber added concrete (W/mK)

4. Conclusion

From the tests that we have performed we came to the following conclusions:

- Increasing fiber dosage in fluid concrete brings about a decrease slump. This is an important feature in terms of the cohesion of fresh concrete, even if it is seen as a negative effect on the workability.
- For 7 and 28 days compressive strength test, as the fiber ratio increased, the compressive strengths decreased by approximately 5%. However, it is observed that this decrease is within the standards of compressive strength.
- As a result of the 28 days flexural strength results, the increase in fiber ratio caused an increase in bending strength which is in agreement with Topcu et al [13] and Acıkgenc et al [10].
- As the fiber dosage increased, the water absorption rate and the ultrasonic velocity increased, but the thermal conductivity coefficient decreased. It was thought that the increase of fiber dosage will contribute to thermal insulation by decreasing the thermal conductivity value.
- Generally, the use of polypropylene fiber added concretes does not technically cause a troublesome situation, but provides numerous benefits to the concrete.
- In parallel with the studies of Sumer and Saribiyik [11] it can be said that the use of polypropylene 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.
- Research for new types of concrete is required to satisfy the current needs in construction industry. Polypropylene fiber added to concrete will be a good substitute to meet these demands.

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