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Combined Effect of Colemanite and Polypropylene Fiber on Properties of Cement Mortar

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ABSTRACT

Turkey is one of the richest countries in the world in terms of boron mineral reserves. The most commercially used boron mineral in Turkey is colemanite. Although there are some studies on the use of colemanite in concrete, there is still a gap in the literature. In this study, first of all, the use of colemanite in mortar samples was investigated by substituting different ratios of colemanite for cement. In addition, polypropylene fiber was added in different ratios by volume, and an evaluation was made on the combine effect of colemanite and fibers on mortar samples. For this purpose, colemanite was substituted for cement in mortar samples at 5% and 10% cement by weight. Polypropylene fibers were added to the mortars produced with colemanite at a rate of 0.4% and 1.2% by volume. In the study, flow tests, capillarity, water absorption, flexural, compressive, and ultrasonic velocity tests were performed on mortar samples, respectively. According to the test results, it was observed that the flow values of the mortar samples produced with colemanite increased compared to the control mixture. It was found that the addition of 10% colemanite instead of cement negatively affected the capillarity, water absorption, flexural and compressive strength, and UPV values of the mortar specimens. 5% colemanite addition had a lower negative effect. 0.4% polypropylene fiber addition resulted in a positive change in the compressive strength and capillarity values compared to the non-fiber specimens.

Keywords: Colemanite, Polypropylene Fiber, Mortar

INTRODUCTION

According to various studies on boron minerals, which is one of the most important strategic mines in the world, it is estimated that the world's total reserve of boron oxide (B_2O_3) is 369.000 million tons of visible reserve, and probable and possible reserves are 1.176.000 million tons. Turkey holds 72.3% of the world's total boron reserves. With this reserve, Turkey is the country with the richest boron resource in the world. In terms of reserves, Turkey is followed by Russia and the USA. With 72.3% of the world's boron reserves, Turkey accounts for 35% of the world's total boron production and dominates 37% of the world market. While the useful life of boron reserves in countries other than Turkey is 60–70 years, the reserve in our country has the potential to meet the boron needs of the whole world for at least 500 years. Although there are many boron minerals in nature, not all of them have the same commercial value.

The main boron minerals with the highest commercial value are Tinkal (Borax), Colemanite, Ulexite, Pandermite and Kernite. The boron minerals mined in Turkey with high commercial value are Tinkal, Colemanite and Ulexite (Yenmez, 2009).

Boron element has many areas of use such as construction and cement industry, glass industry, chemical industry, energy sector, metallurgy, ceramic industry, pharmaceutical and cosmetics industry, paper industry, preservative in wood materials, machinery industry, nuclear industry, agriculture sector, automobile industry (Demirel, 2017).

In some studies on the use of boron in construction materials; Volkman and Bussolini (1992), stated that boron admixtures are known to slow down the hardening and compressive strength properties of concrete and that fine particles are soluble and affect the hardening properties of concrete. Bideci and Bideci (2018), investigated the effect of ground colemanite admixture on cement mortar properties. Firstly, the pozzolanic activity of ground colemanite was determined. Then, the specific gravity, specific surface area, setting start and end times, flow tests and expansion tests of cement mortars with ground colemanite admixture at different ratios (0%, 1%, 3%, 5%, 7%), as well as the compressive strength of the

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mortar samples (2, 7 and 28 days) were determined and compared with the reference sample. According to the test results, it was determined that the setting start and setting end times were prolonged with the increase in the ground colemanite substitution ratio, all cement mortars provided the lowest mechanical properties required by TS EN 197-1 standard (≥42.5 MPa and ≤62.5MPa) and 1%, 3% and 5% colemanite can be used as cement substitute. Yalçın (1996), in the study investigating the effect of colemanite admixture on the physical properties of concrete, stated that cements containing more than 5% colemanite were out of standard in terms of setting time and strength, while cements with 2% colemanite admixture delayed the setting time and caused up to a 28% decrease in compressive strength. Demir and Orhan (2002), in their study on the evaluation of boron wastes as building materials, determined that a material with high porosity and low unit volume weight (light weight) can be produced by mixing pumice with boron waste at a rate of 50% by weight and firing at 900ºC.

Targan (2002) used Kula slag colemanite concentrator waste and betonite colemanite concentrator waste variations as additives in order to save energy in cement production and to eliminate the negative effects of waste materials on the environment. They stated that the physical, chemical and mechanical properties of the cement mixtures were in compliance with Turkish Standards and that the additives used could be used in cement production. Topçu et al. (2006) recommended the use of boron wastes (B_2O_3 ratio 9.63%) produced during tincal production instead of cement (0%, 3%, 7%, 10% by weight instead of cement) in mortars produced by using boron wastes at 3% and lower ratios against the harmful effects of high temperature. Binici et al. (2010) investigated the mechanical strength and sulfate resistance of mortars containing basaltic pumice, barite, colemanite and blast furnace slag. Various proportions of pumice, barite, colemanite and blast furnace slag were used instead of cement and Rilem-Cembureau standard sand. The 7-day mortar specimens showed the highest flexural strength of the reference specimen and the lowest flexural strength of the specimens with 0.75% colemanite. The 7-day mortar samples had the highest compressive strength value of the reference sample and the lowest compressive strength value of the sample with the highest colemanite content and the longest hydration time. Colmanite decreased early age strength. Ustabaş investigated the usability of colemanite and ulexite in cement. Colemanite and ulexite, which were cleaned from foreign materials and ground, were substituted with CEM I 42.5 R class cement at 0.5%, 1%, 2%, 2%, 3%, 4% and 5% of the cement mass. In the other phase of the study, clinker was fired at 1300 oC by mixing with colemanite and ulexite. After the cooked mixture cooled down, new cements were produced by grinding in the laboratory. Expansion constancy, standard consistency, setting start and end times of boron and normal cements were measured. Compressive and flexural strengths of boron cement mortar samples produced according to TS EN 196-1 were determined. It was found that the use of colemanite and ulexite did not improve the cement properties.

Polypropylene fibers (PPF) are frequently used in cementitious mixtures to prevent shrinkage. It is also known to have significant effects on ductility, toughness, and impact resistance. PPF are preferred in slabs, industrial floors, precast elements, shotcrete applications, and some water structures due to these properties (Behnood and Ghandehari, 2009). According to the literature, there are many studies about fibercontaining cementitious systems. However, studies in which it is used together with colemanite in mortar mixtures are lacking.

In this study, the effect of using PPF and colemanite admixtures together or separately at certain ratios on mortar properties was investigated. It is aimed to reduce cement consumption by showing pozzolanic activity of colemanite. The expected results include maintaining or increasing the compressive strength of the mortar, reducing the damage of cement to nature and reducing the cost of concrete by using colemanite instead of cement. Within the scope of the research, 5% and 10% colemanite was added instead of cement by weight. In addition, 0.4% and 1.2% PPF was added to the mixture by volume. Capillarity, water absorption, flexural, compressive, ultrasonic velocity and flow tests were performed on the mortars produced during the study. The changes in the physical and mechanical properties of the concrete mortar caused by colemanite and PPF were observed.

MATERIALS AND METHODS

Materials

The cement used was CEM I 42.5 R. The chemical composition and physical properties of cement are given in Table 1. The sand used in the experimental study was standard Rilem Cembureau type according to TS EN 196-1. Colemanite was obtained from Etimaden, Kütahya. The physical and chemical properties of the Colemanite used are given in Table 2. X-ray diffraction analysis of colemanite is also shown in Figure 1. Polypropylene fiber properties used in the study are presented in Table 3.

Table 1. Physical, chemical and mechanical properties of cement

Chemical properties	**%**
SiO_2	20.5
Al_2O_3	4.65
Fe_2O_3	3.40
CaO	62.7
MgO	1.02
SO_3	2.21
TiO_2	-
Na_2O	0.18
K_2O	0.41
CI	0.01
Physical and Mechanical Properties	
Specific surface, cm^2 /g	3510
Specific gravity	3.12
Initial setting time	153
Final setting time	188
Strength	
2 d, MPa	30.2
7 d, MPa	51.1
28 d, MPa	62.2

Table 2. Physical, chemical and mechanical properties of Colemanite.

Chemical properties	**%**
CaO	27.00 ± 1.00
B_2O_3	40.00 ± 0.50
SiO_2	4.00 - 6.50
SO_4	0.60 max
Fe_2O_3	0.08 max
Al_2O_3	0.40 max
MgO	3.00 max
SrO	1.50 max
Na_2O	0.50 max
Humidity	1.00 max
LOI	25.00 max
Physical and Mechanical Properties	
Specific surface, m^2 /g	3.30
Specific gravity	2.50
Density, g/cm^3	0.971
Moleculer weight, g/mol	411.08
Heat capacity, J/g^{o}C	15.4
Thermal conductivity, W/mK	0.526
Color measurement	88.53
Surface tension, mN/m	64.78

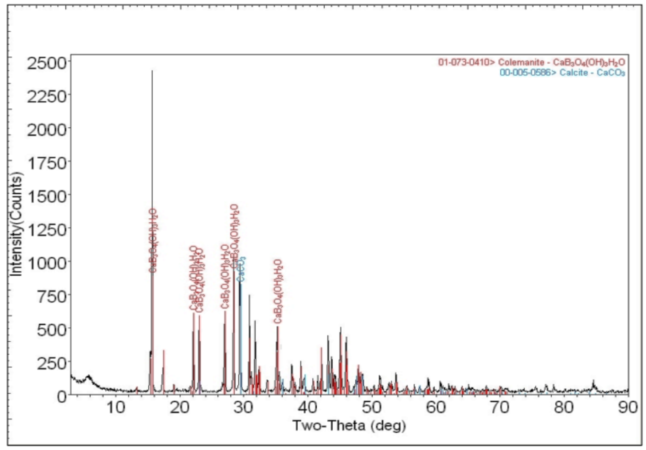

Figure 1. X-Ray diffraction analysis of Colemanite.

Table 3. Properties of the PPF.

Properties	**PPF**
Specific gravity	1.14
Length (mm)	6
Tensile strength (MPa)	900
Melting point (^{o}C)	260
Water absorption (%)	4-5

Methods

The water/binder ratio of the mortar mixtures was kept constant at 0.5 and sand/binder 3.0 throughout the study. Colemanite was added instead of cement at 5% and 10% of the cement binder weight. PPF was used at 0.4% and 1.2% by volume. Mixing ratios are presented in Table 4. Mortar specimens were produced in prismatic molds with dimensions of 40x40x160 mm. Flow test, compression and flexural, UPV, water absorption and capillarity tests were performed on the mortar specimens. The production stage of the mortar specimens and the experiments performed are presented in Figure 2. According to TS EN 1015-3, flow table tests were conducted to determine mortar flowability, with and without admixtures. After 24 h, the specimens were demoulded and cured in 28 day. The strength tests of the specimens were conducted at 28 days of age according to TS EN 1015-11. For flexural strength test, three prismatic specimens from each mixture were used and tested by one-point loading configuration with span of 10 cm. The compressive strength test was performed using six broken pieces of test prisms remained from flexural strength test. The flexural strengths were determined by taking the average of three test results whereas the compressive strengths were determined as the average of six test results. UPV was applied to the samples with the method specified in ASTM C 597. Water absorption values of mortar samples were obtained from 40x40x160 mm sized samples according to Equation 1.

Water Absorption (%)= $\{(A_{SSD}-A_{OD})/(A_{OD})\}*100$ (1)

Here; A_{OD}: Oven dry (g); A_{SSD}: Saturated surface dry weight (g)

For the capillary water absorption value, 40x40x160 mm sized specimens were produced. The specimens were cured in water for 28 days and then dried in an oven to constant mass. The part of the mortar surface in contact with water was placed on supports adjusted along the 4x16 cm surfaces so that the mortar surface was immersed in 5 mm water. The side surfaces were covered with water-repellent tape (Figure 2). The amount of water absorbed for 1, 5, 10, 20, 30, 60 and 1440 min was obtained according to Equation 2.

$I= m_t/axd$ (2)

Here;

I= Capillary water absorption (mm)

a= Surface area in contact with water (mm^2)

m_t= Amount of water absorbed at time t (g)

d= Density of water (g/mm^3)

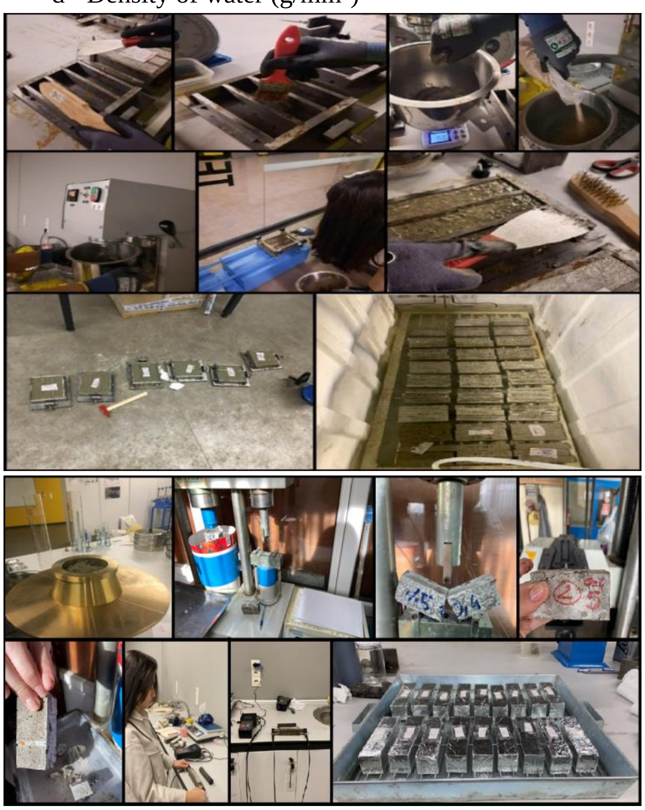

Figure 2. Preparation of mortar samples and applied tests.

Table 4. Sample mixing ratios (g).

Mixing Code	Sand (g)	Cement (g)	Water (g)	Colemanite (%)	PPF (%)
CS	1350	450	225	-	-
C5	1350	427.5	225	5	-
C10	1350	405	225	10	-
C5/0.4F	1350	427.5	225	5	0.4
C5/1.2F	1350	405	225	5	1.2
C10/0.4F	1350	427.5	225	10	0.4
C10/1.2F	1350	405	225	10	1.2

RESULTS AND DISCUSSION

Physical Properties

An increase in flow values was observed with the addition of colemanite in both ratios instead of cement in mortar samples. However, the flow values of the mortar samples decreased after the addition of PPF in the colemanite admixed mortars (Figure 3). Mortar sample C10 gave the best results compared to the control sample, while the sample with the lowest flow value was C5/1.2F. Similar findings related to the increase in the flow values of mortar samples with colemanite admixture were obtained by Ustabaş (2012) in study.

Figure 4 shows the capillary water absorption of mortars with different colemanite ratios. According to Figure 4, it is seen that the addition of colemanite decreases the amount of capillary water absorbed, but the water absorption increases with time. After 120 minutes, the difference between the capillary water absorption values between the colemanite-added mortars and the control sample closes. At the end of 1440 minutes, the capillary water absorption values of the colemanite additives and the control sample are similar. The highest capillary water absorption value is 6.10 mm (Figure 4).

In Figure 5, capillary water absorption values of colemanite-admixed mortar samples after fiber addition are presented. With the addition of fiber, capillary water absorption rates of colemanite-admixed mortars were partially reduced compared to the control sample.

In Figure 6, water absorption values of mortar samples are presented. Water absorption values increased with the addition of colemanite compared to the control sample. This increase even more with the addition of fiber to colemanite admixed mortars. Similar results were obtained by Durgun et al. (2022) in their study. The addition of PPF to the mixtures increased the 28 and 56-day water absorption ratios compared to the mixtures without fiber. Increasing the fiber ratio from 0.5% to 0.75% or 1% in the mixtures increased the water absorption ratios more significantly. However, the increasing ratio in water absorption decreased with the increase of fiber content in the mixtures containing colemanite waste (Durgun et al., 2022).

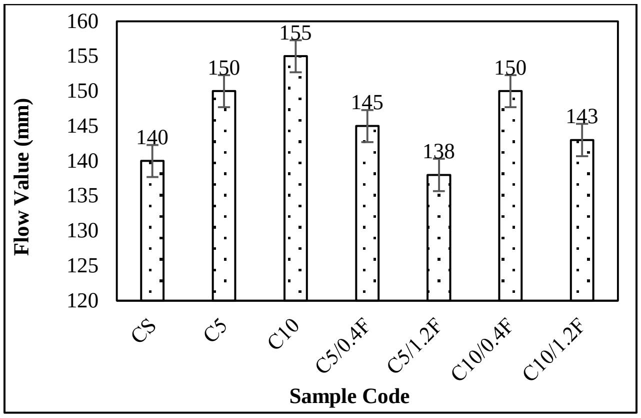

Figure 3. Flow table test results of samples

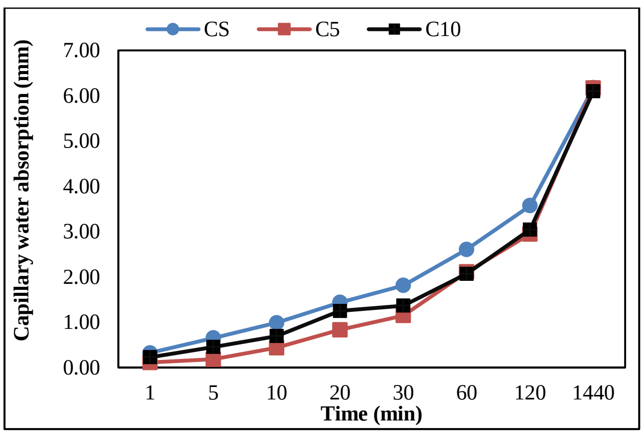

Fig. 4. Effect of the addition of Colemanite at different rates on the Capillary water absorption

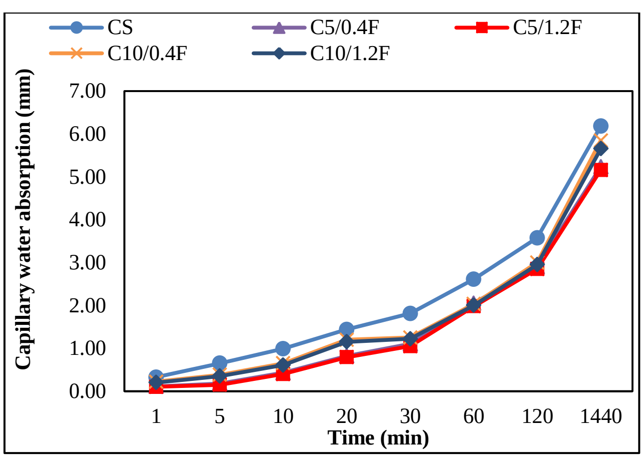

Fig. 5. Effect of the addition of Colemanite and PPF at different rates on the capillary water absorption

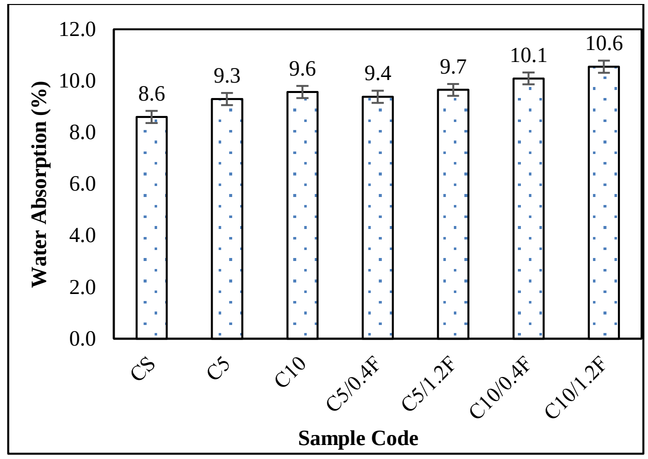

Fig 6. Water absorption ratios of mortars.

Mechanical properties

The compressive and flexural strengths of mortar samples are presented in Figure 7. It can be seen that both compressive and flexural strengths decreased as the amount of colemanite increased. However, the addition of PPF slightly increased the compressive strengths, and the closest result to the control was obtained in the C5/0.4F series with a strength of 46.96 MPa. Similarly, the effect of fiber reinforcement on flexural strengths was also limited in this study. The highest flexural strength was obtained in the control specimen with 9.04 MPa, while the closest result was obtained in the C5/0.4F mortar specimen with 6.26 MPa. In the study where a correlation was established between UPV and compressive and flexural strengths, the best value was obtained in the control specimen (Figure 8). However, when colemanite was added, the closest result was obtained in the C5 series with a UPV of 4.103 km/s. With the addition of PPF reinforcement, the closest result was obtained in the C5/1.2F series with a UPV of 3.973 km/s. According to Neville (1995), concretes with UPV values between 3.5-4.5 km/s are classified as high quality concrete. The value of the mortar samples produced in this study is within this range. Similar to the strength results in this study, Durgun et al. (2022), Celik et al. (2014), Kula et al. (2001), Sevinç et al. (2017) found a negative effect on compressive and flexural strengths with increasing colemanite content in mortar samples.

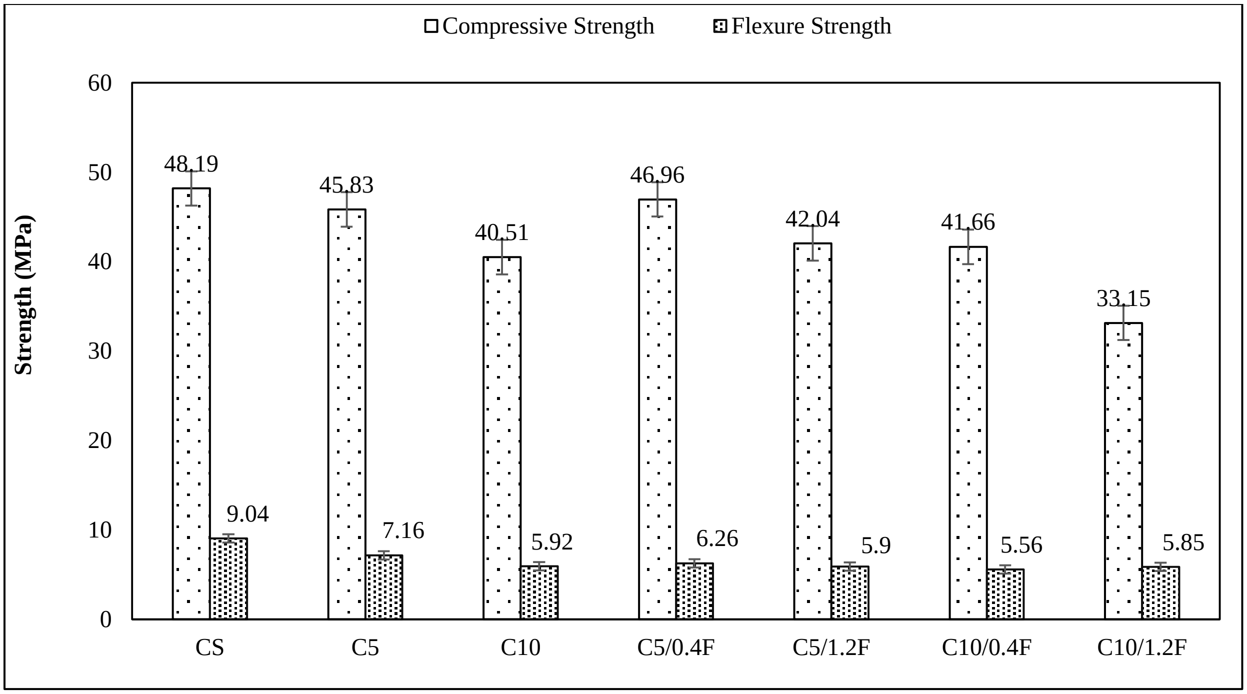

Figure 7. Compressive and flexural strengths of mortar samples.

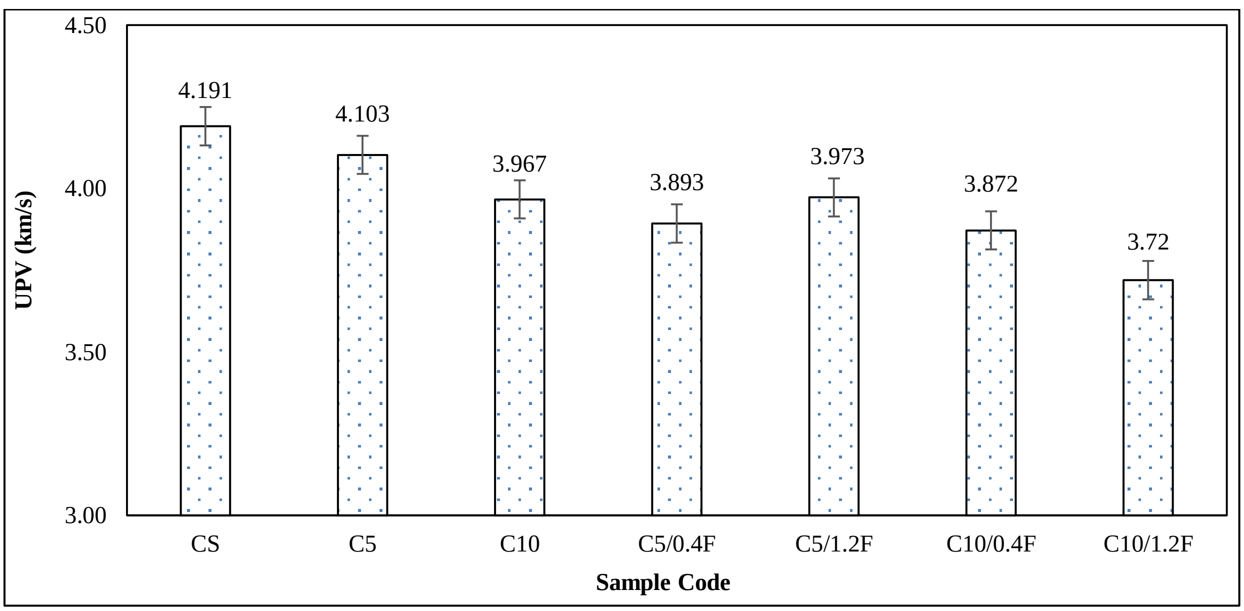

Figure 8. UPVs of mortar samples.

CONCLUSION

The following conclusions were reached within the scope of this study.

1- When colemanite was replaced with cement, an increase in flow values was observed compared to the control specimen. The flow values decreased after the addition of PPF in colemanite admixed mortars and flow values close to the control sample were obtained.

2- In terms of water absorption, the samples containing Colemanite exhibited a higher water absorption rate compared to the control sample. The mortar mixtures with PPF also absorbed slightly more water than the control sample, which was attributed to the water absorbing properties of the fibers.

3- The addition of colemanite instead of cement decreased the compressive and flexural strength of the mortar specimens. This decrease increases with the increase in colemanite content. The addition of 0.4% PPF increased the compressive strength of the mortars produced with colemanite, while the addition of 1.2% PPF decreased the compressive strength. Among the mortar specimens, the C5/0.4F specimen showed the best performance in terms of compressive and flexural strength and was close to the control specimen.

4- The addition of 5% colemanite did not reduce the UPV compared to the control sample, while the addition of 10% colemanite resulted in a lower UPC. The addition of PPFs caused the mortar to agglomerate, making it difficult to place in the molds and reducing workability. The agglomerated mortar is thought to create voids leading to slightly lower ultrasonic velocities compared to the control sample. UPV values ranging from 3.65 to 4.5 km/s were obtained for the mortar samples. Therefore, the mortar samples produced were considered to be of high quality.

DECLARATIONS

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Author's contribution

All authors contributed equally to this work.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare no competing interests in this research and publication.

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