Mechanical and Physical Performance of Portland Cement Composites with Partial Replacements of Metakaolin and Ulexite

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Abstract- Fabricating green binding materials are gaining a great importance in the construction sector recently. This rising interest is based upon the need for more sustainable and environment-friendly alternatives to conventional cementitious materials by utilizing waste materials and mineral by-products in the binding matrices through partial or complete replacement with Portland cement. In this paper, an experimental investigation was conducted to examine the effect of using a boron waste, namely ulexite, along with metakaolin as partial replacements with Portland cement. By this means, flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were carried out on twelve different specimens, including the amount of ulexite of 5% and 7%, metakaolin of 10% and 20%, and amount of superplasticizer additive of 1%. The main conclusions of this work showed that using ulexite and metakaolin up to certain percentages is beneficial in terms of mechanical and physical properties. A further increase in the addition can lead to a decrease in the performance of the matrix.

Keywords: Portland cement, Boron, Ulexite, Metakaolin, Superplasticizer

1. Introduction

Boron is an essentially valuable mineral that is used in many industries (nearly 500 fields), from technology and medicine to nuclear waste storage and space exploration, including material engineering and construction sectors such as cement [1,2], and its use is increasing day by day [3].

Boron does not exist by itself in nature. It exists as boric acid or borates (boron minerals) combined with oxygen and other elements [4]. Boron, which has several amorphous and six polymorphic allotropes, is considered the most rigid element after diamond [5]. The world's largest boron reserves are located in Turkey, the USA and Russia. However, Turkey possesses the most of the world's boron reservations by 72.1%. There are 230 different boron minerals in the nature. The most important ones are tincal, colemanite, ulexite, kernite, pandermite, szaybelite and hydroboracite in terms of commercial importance [6].

Boron usage in cement is limited due to hardening and other related problems worldwide. If these problems can be eliminated, the widespread use of boron compounds as additives in cement and concrete production would be possible. Thus, some technological developments will be added to cementitious composites, such as additional fire resistance and radiation impermeability [7,8].

Metakaolin

Metakaolin (MK) is produced by heating kaolinite (China clay) at (600-850) °C for 30–60 minutes. It has high pozzolanic activity. Therefore, it can replace cement because of its pozzolanic properties. The engineering properties of MK are controlled as it is not a by-product [9-11].

MK is a material that includes a high amount of SiO_2 and Al_2O_3. The silica and alumina in the structure of metakaolin form new calcium silicate hydrate (CSH) structures and alumina-containing phases (C4AH13, C2ASH8, C3AH6) by reacting with $Ca(OH)_2$ formed as a result of hydration of cement. Thanks to these comprised products, it increases mechanical properties and durability in cement and concrete produced [12,13].

Moreover, it was shown that MK replacement in cement could lower the normalized CO_2 emissions and resource consumption [14]. MK has to go through a burning process like cement, whereas the temperature of MK production is between 700 °C–900 °C as opposed to 1450 °C in cement production. Therefore, a significant amount of CO_2 emissions will be reduced by using MK. In terms of sustainability aspects, this feature can help MK use in concrete production in the future [11].

Boron Compound Usage in Cement

Until now, there have been some studies that different amounts of boron compounds are used in cement production and evaluated in terms of durability properties. Uğurlu et al. [15] investigated the effects of clay wastes containing boron compounds on the mechanical properties of mortar. They found that clay wastes that occurred during tincal production can be utilized in cement.

Targan et al. [16] added colemanite waste separately to the Kula slag and bentonite mixture. They stated that different proportions of colemanite waste could be used in cement production, and clinker production would achieve energy savings [16,17].

Boron compounds, especially colemanite, are used in the construction industry due to their durability-increasing, resistance to heat and radiation and isolation-providing properties. Moreover, it has been proved that cement with boron addition was more durable than Portland cement (PC) and had a low heat of hydration [17,18]. Concretes containing cement with boron are more impervious and durable to external factors. Also, these concretes' water absorption and chlorine permeability are 30% less than concretes, including PC [17].

In Anuk's study [18], the use of MK instead of cement increased the flexural and compressive strengths of the mortars and decreased the expansion values that may occur due to alkali-silica reaction (ASR), also decreasing the amount of water absorption and permeability. The highest compressive and flexural strengths were obtained using 15% MK in mortars. In addition, the lowest values of expansion, water absorption and permeability due to the effect of ASR and sulfate were observed in mortars containing 15% MK.

Ulexite

Ulexite is one of the important borates. Its chemical formula is $NaCaB_5O_9.8H_2O$. It is a boron mineral glassy, white or non-coloured, transparent to opaque, and soluble in water. According to the Mohs Hardness Scale, its hardness is 2.5, and its specific weight is 1.95–2 gr/cm. [19,21]

Ulexite, a mineral-rich type of boron, plays a significant role in heat, sound and radiation insulation, glass, ceramics and fertilizer industries and is also used in boric acid and borax production [18,22].

Although there are few studies on ulexite in building materials and the construction sector, some studies show that ulexite might be used in cement [23,24]. In this study, the mechanical properties of Portland cement with metakaolin and ulexite replacement have been investigated.

2. Materials and Methods

2.1. Materials

The materials used in this study are Portland cement CEM I 42.5 R, ulexite, metakaolin, superplasticizer, Rilem sand as fine aggregates and potable tap water. Characteristics of the materials are shown below:

Cement: Portland cement CEM I 42.5 R, manufactured by Adana Cement Industry, was used. In order to use fresh cement, all necessary measures were taken, and agglomeration was prevented by keeping the cement in special protective containers. The physical and chemical properties of the cement are presented in Table 1.

Table 1. Chemical and physical properties of cement (CEM I 42,5 R)

Chemical compounds	Results (%)
S_iO_2	19.55
Al_2O_3	5.31
Fe_2O_3	4.15
Mg_2O_3	0.06
CaO	62.30
MgO	3.14
SO_3	2.55
Na_2O	0.36
K_2O	0.88
Free CaO	0.31
LOI.	1.73
Specific density	3.10 g/cm^3

Ulexite: Dried ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$) from Eti Mine Bigadic Boron Works (Balikesir, Turkey) is used in this study. The physical and chemical properties of the ulexite are shown in Table 2.

Table 2. The chemical compound of ulexite (-45 μm)

Component	Content (%)
B_2O_3	37±1
CaO	19
SiO_2	≤4
Fe_2SO_3	≤0.04
Al_2O_3	≤0.25
MgO	≤2.50
SrO	≤1
Na_2O	≤3.50

Metakaolin: Metakaolin used in this study was obtained from Kaolin Endustriyel Mineraller Inc. (Istanbul, Turkey). Its chemical composition is presented in Table 3. Its mineralogical composition is quartz ∼ 8, mica ∼ 4, kaolinite – traces, amorphous phase ∼ 87, and the others ∼ 1).

Table 3. Chemical composition of metakaolin

Chemical Composition	Amount (%)
SiO_2	56.10
Al_2O_3	40.23
Fe_2O_3	0.85
SO_4	0.55
CaO	0.19
MgO	0.16
K_2O	0.51
Na_2O	0.24
LOI.	1.10

Superplasticizer: Polydos® TS 14 super plasticizing concrete admixture was used in this study. The recommended dosage of the chemical compound in the official description varies between 0.6 and 2.0 kg per 100 kg of the binder.

In this study, preliminary studies were conducted to estimate the optimal amount. It was found that the addition of 2% and 1.5% of Polydos® TS 14 by mass delayed the setting time too much. Following the results, it was observed that the most optimal amount of Polydos® TS 14 is 1% by the mass of the binder or 4.5 g.

Polydos® TS 14's technical properties are shown in Table 4.

Table 4. Technical properties of Polydos® TS 14

Technical properties	Description
Chemical contents	Polycarboxylate based
Appearance-colour	Brown liquid
Density	1.05±0.02 kg/L
pH value	4.5±1
Chloride content (Cl)	<0.1%
Alkali content	<4%
Freezing point	-4 ºC

Rilem sand: Standard Rilem sand produced by Trakya Cement Factory (Kırklareli, Turkey), matching the regulations stated in TSE EN-196, was used as fine aggregates while mixing the preparation.

Water: Potable tap water was used to prepare the blends and store the hardened samples.

2.2. Methods

This experimental study was conducted to determine the mechanical and physical performances of Portland Cement composites with partial replacements of metakaolin and ulexite.

This experimental study was conducted in Istanbul Gelisim University's building materials laboratory in 2022. Since this study does not contain any human or animal subjects, ethics committee approval is not applicable.

The specimens were divided into 12 groups according to their ingredients. One of the samples was the control group. Flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were applied on all 12 specimens during 90 days with intervals of 2, 7, 28, and 90 days.

Necessary data were collected from the results of the experiments. The results were shared in the results section.

2.3. Preparation of the Samples

Twelve different samples were prepared with the replacement of ulexite of 5% and 7%, metakaolin of 10% and 20%, and the addition of a superplasticizer additive of 1%, in compliance with BS EN 196-1. The samples were organized for the tests of fresh and hardened properties separately and named based on their ingredients. The prepared samples were immersed in water on the second day of curing and kept at 20±2 ºC.

The amounts and percentages of the materials are stated in Tables 5 and 6.

Table 5. Percentage of materials in the blends

Mix ID	Cement (%)	Sand (%)	Ulexite (%)	Metakaolin (%)	W/C ratio	TS 14 (SP) (%)
Control	**100**	**100**	**0**	**0**	**0.5**	**0**
5UX	**95**	**100**	**5**	**0**	**0.5**	**0**
7UX	**93**	**100**	**7**	**0**	**0.5**	**0**
SP	**100**	**100**	**0**	**0**	**0.4**	**1**
5UX-SP	**95**	**100**	**5**	**0**	**0.4**	**1**
7UX-SP	**93**	**100**	**7**	**0**	**0.4**	**1**
MK20	**80**	**100**	**0**	**20**	**0.5**	**0**
MK30	**70**	**100**	**0**	**30**	**0.6**	**0**
MK20-SP	**80**	**100**	**0**	**20**	**0.5**	**1**
MK30-SP	**70**	**100**	**0**	**30**	**0.5**	**1**
5UX-MK20	**75**	**100**	**5**	**20**	**0.5**	**0**
5UX-MK30-SP	**75**	**100**	**5**	**20**	**0.5**	**1**

Table 6. Amount of materials in the blends

Mix ID	Cement (g)	Sand (g)	Ulexite (g)	Metakaolin (g)	Water (g)	TS 14 (SP) (g)
Control	**450**	**1350**	**0**	**0**	**225**	**0**
5UX	**428**	**1350**	**22.5**	**0**	**225**	**0**
7UX	**419**	**1350**	**31.5**	**0**	**225**	**0**
SP	**450**	**1350**	**0**	**0**	**203**	**4.5**
5UX-SP	**428**	**1350**	**22.5**	**0**	**203**	**4.5**
7UX-SP	**419**	**1350**	**31.5**	**0**	**203**	**4.5**
MK20	**360**	**1350**	**0**	**90**	**225**	**0**
MK30	**315**	**1350**	**0**	**135**	**270**	**0**
MK20-SP	**360**	**1350**	**0**	**90**	**225**	**4.5**
MK30-SP	**315**	**1350**	**0**	**135**	**225**	**4.5**
5UX-MK20	**338**	**1350**	**22.5**	**90**	**225**	**0**
5UX-MK30-SP	**293**	**1350**	**22.5**	**90**	**225**	**4.5**

2.4. Experiments

Following the preparation and curation of the samples, the flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were conducted over 90 days with intervals of 2, 7, 28, and 90 days.

3. Results and Discussion

3.1. Flow Table Test

In order to demonstrate the spreading properties of the samples flow table test was applied to the fresh mortars.

It was seen that all samples behaved differently; the mixture MK20-SP showed a drastically good result when the control sample (PC) was taken as a reference. 7UX-SP, MK20-SP and 5UX-MK20-SP gave the closest values when it was compared to the control sample (Table 7).

Although adding 20% of metakaolin caused low flow ability, adding 1% of superplasticizer had very positive effects on the flow ability of the samples.

The test showed that the addition of ulexite reduces the spreading of the mortar, and metakaolin affects the spreading characteristics significantly, increases W/C up to 0.6, and facilitates flow ability.

The flow table results were compared with plain Portland cement mortar flow results, which was 17.75 cm spread. The comparison of 5UX-MK20-SP was approximately the same with PC or 0.5 (100.70%). Comparison percentages of the samples according to the control sample (PC) were presented on Tab.

Table 7. Flow table test results

Sample name	D_1 (cm)	D_2 (cm)	D_3 (cm)	D_4 (cm)	D_{avg} (cm)	D_0 (cm)	Results (%)
Control	17.5	18	18	17.5	17.75	10	77.5
5UX	12.5	12	12.5	12	12.25	10	22.5
7UX	15.5	16	15.5	16	15.75	10	57.5
SP	15	15.5	15.5	15.5	15.375	10	53.75
5UX-SP	15	15	15.5	15.5	15.25	10	52.5
7UX-SP	17.5	17.5	17.5	17.5	17.5	10	75
MK20	12.5	12	12	12.5	12.25	10	22.5
MK30	16.5	16	16	16	16.125	10	61.25
MK20-SP	17.5	17.5	18	18.5	17.875	10	78.75
MK30-SP	15.5	15.5	15	15	15.25	10	52.5
5UX-MK20	12	11.5	12	12	11.875	10	18.75
5UX-MK20-SP	16.5	17	17	16.5	16.75	10	67.5

Table 8. Flow table test results compared to the control sample

Sample name	Comparing to PC
Control	100%
5UX	69.01%
7UX	88.73%
SP	86.62%
5UX-SP	85.92%
7UX-SP	89.59%
MK20	69.01%
MK30	90.85%
MK20-SP	100.70%
MK30-SP	85.92%
5UX-MK20	66.90%
5UX-MK20-SP	94.37%

3.2. Setting Time

The samples' initial and final setting times were measured using the VICAT apparatus with a needle of ⌀1.3. The results were provided on Table 8.

The samples including ulexite gave longer setting time results, whereas the samples including metakaolin gave shorter setting time results. It could be inferred that the addition of ulexite prolonged and metakaolin shortened the setting time of the mortar.

Table 9. Setting time test results

Sample name	Setting time (min)
Control (PC)	**178.34**
5UX	**356.67**
7UX	**561.88**
SP	**230**
5UX-SP	**522.50**
7UX-SP	**944**
MK20	**118.75**
MK30	**207.50**
MK20-SP	**279.29**
MK30-SP	**218.34**
5UX-MK20	**276.43**
5UX-MK20-SP	**525.63**

3.3. Compressive Strength

Second, seventh, 28th and 90th-day compressive strength results were measured and noted. The results are shown in Table 9. The sample with ID 'SP' had the highest compressive strength values on the second, seventh, 28th and 90th days, 7UX-SP had the lowest compressive strength value on the second day, and 7UX had the lowest compressive strength value on the 7th, 28th and the 90th days.

Table 10. Compressive strength results (MPa)

Sample name	2-day	7-day	28-day	90-day
Control (PC)	24.85	30.49	36.97	38.47
5UX	14.06	18.03	26.03	33.35
7UX	9.65	17.05	21.43	27.03
SP	25.45	42.46	44.20	46.72
5UX-SP	13.17	33.86	39.17	45.58
7UX-SP	0.00	26.36	40.14	40.87
MK20	16.63	33.65	34.54	46.54
MK30	20.18	22.31	26.46	36.59
MK20-SP	16.12	27.68	38.28	46.57
MK30-SP	14.16	26.18	40.49	44.53
5UX-MK20	10.19	29.15	33.81	45.17
5UX-MK20-SP	7.18	23.28	36.64	43.93

It is calculated that the addition of 5% ulexite only by mass, or 22.5 g, decreases the compressive strength by approximately 40% on the 7th day, 30% on the 28th day, and 13% on the day 90th. Meanwhile, increasing ulexite proportion to %7 only, compressive strength decreased by approximately 44% on the 7th day, 42% on the 28th day, and 30% on the 90th day. It can be concluded that increasing ulexite by more than 5% decreases compressive strength drastically. This occurs due to the high calcium content of ulexite.

The addition of 1% Polydos® TS 14 increased compressive strength results as of the second day. Adding 1% Polydos® TS 14 superplasticizer and 5% ulexite increased compressive strength by approximately 11% on the 7th day, 5% on the 28th day, and 18% on the 90th day. However, its 2-day compressive strength was less than 53%. Moreover, when 7% of ulexite and 1% of Polydos® TS 14 superplasticizer were added, compressive strength results decreased compared to 5% of ulexite and 1% of SP and showed an increase when compared to the control sample. The results showed that the ideal amount for ulexite was 5%.

The samples that metakaolin was added showed low compressive strength results according to the control (PC) sample on the second day. However, their compressive strength results increased from the seventh day and gave higher results than the PC sample. The results showed that adding 30% of metakaolin led to the sample being more durable in a short time, nevertheless adding 20% of metakaolin gave more durable samples. In addition to that adding superplasticizer had positive effects.

Whereas ulexite and metakaolin were mixed the results showed that the samples became more durable in terms of compressive strength and they became more durable when a superplasticizer was added to the sample.

The changes in the samples day by day are shown in Figure 1

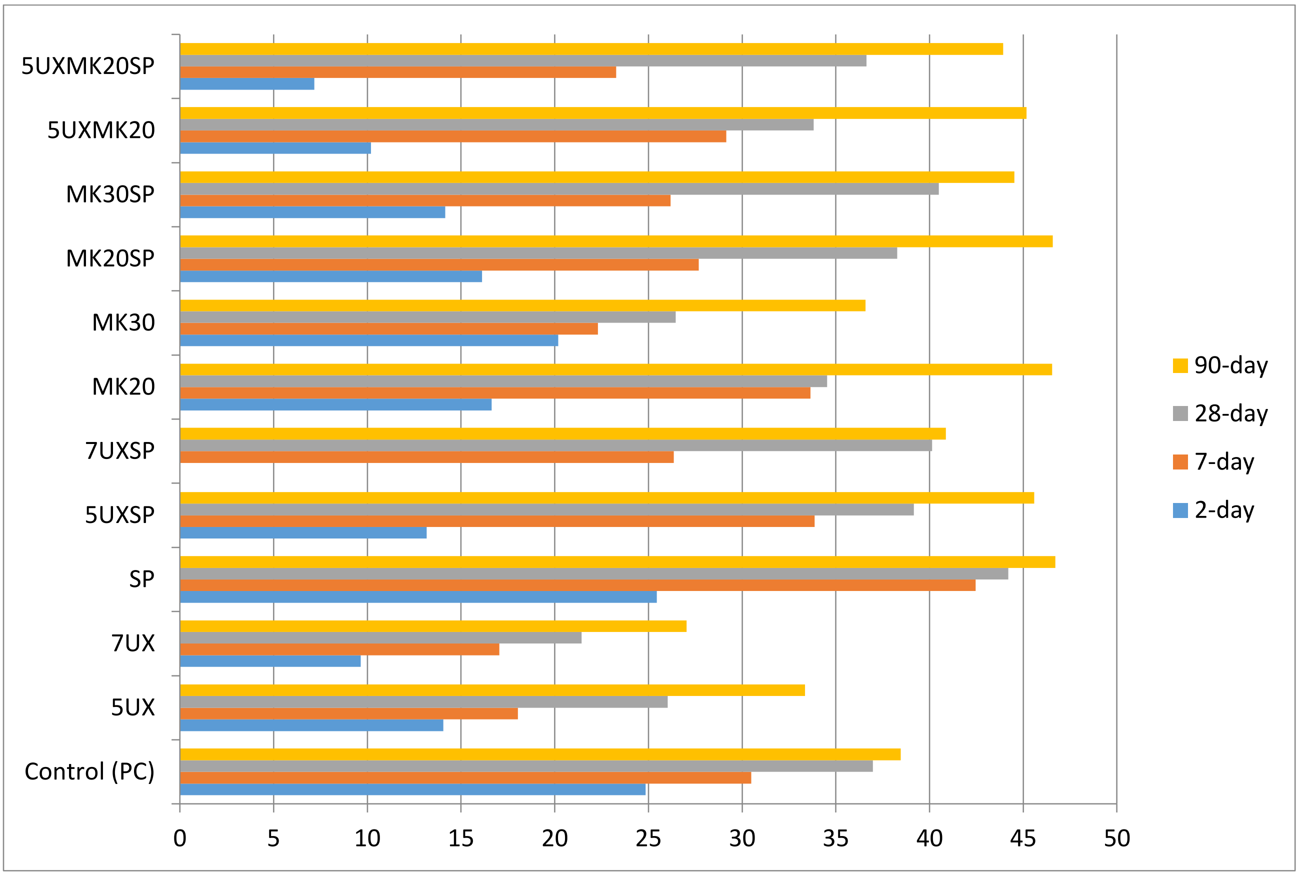

Figure 1. Comparison of compressive strength values as per 2nd, seventh, 28th and 90th days

3.4. Flexural Strength

Two, seven, 28- and 90-day flexural strength results were measured and noted. The results are shown in Table 10. SP sample had the highest flexural strength values on the 2nd, 7th and 28th days. However, MK30-SP had the highest flexural strength value on the 90th day. 7UX-SP had the lowest flexural strength value on the second day, and 7UX had the lowest flexural strength value on the 7th, 28th and 90th days.

Table 11. Flexural strength results (MPa)

Control (PC)	**5.95**	**7.10**	**8.03**	**8.57**
5UX	**3.72**	**5.31**	**6.19**	**7.25**
7UX	**2.62**	**4.30**	**6.13**	**6.12**
SP	**6.37**	**9.45**	**9.72**	**9.28**
5UX-SP	**3.78**	**7.49**	**7.76**	**8.78**
7UX-SP	**0.00**	**7.15**	**8.50**	**9.82**
MK20	**5.20**	**7.80**	**8.83**	**8.24**
MK30	**5.13**	**5.79**	**7.75**	**8.82**
MK20-SP	**4.86**	**7.67**	**8.71**	**9.02**
MK30-SP	**4.40**	**6.37**	**9.27**	**9.79**
5UX-MK20	**2.70**	**6.51**	**9.41**	**9.47**
5UX-MK20-SP	**2.30**	**5.90**	**9.34**	**8.99**

Flexural strength results of the samples 5UX and 7UX, which were obtained by mixing plain Portland cement with UX in the proportions of 5% and 7%, displayed lower than PC for 90 days. On the other hand, the sample mixed with only 1% Polydos® TS 14 showed a higher result than the control sample during 90 days. The samples created by adding ulexite and superplasticizer (5UX-SP and 7UX-SP) eliminated the adverse conditions and showed higher results than the control sample (PC) as of the 7th day. Moreover, the addition of MK gave similar results to the control sample. However, adding 30% of MK prolonged the flexural strength results slightly. Nevertheless, the samples with MK addition exhibited slightly higher results on the 90th day than the control (PC) sample.

It was observed that as the amount of added UX increased, the setting time increased and therefore the flexural strength results were poorer than the control sample. When 1% SP was included in the samples, it was seen that the results were healed. Also, although adding 30% MK had already slightly better results compared to the control sample, adding 1% superplasticizer healed the results and led to give better results. In these cases, it is clear that the addition of SP removes the negative effects.

The best results of the samples according to the days; SP (1% Polydos® TS 14 superplasticizer) with 6.37 MPa on the 2nd day, SP with 9.45 MPa on the 7th day, SP with 9.72 MPa on the 28th day and MK30-SP (30% MK and 1% Polydos® TS 14 superplasticizer) with 9.79 MPa on the 90th day. According to the results, it can be concluded that adding superplasticizer had positive effects on the samples.

The changes in the samples day by day are shown in Figure 2.

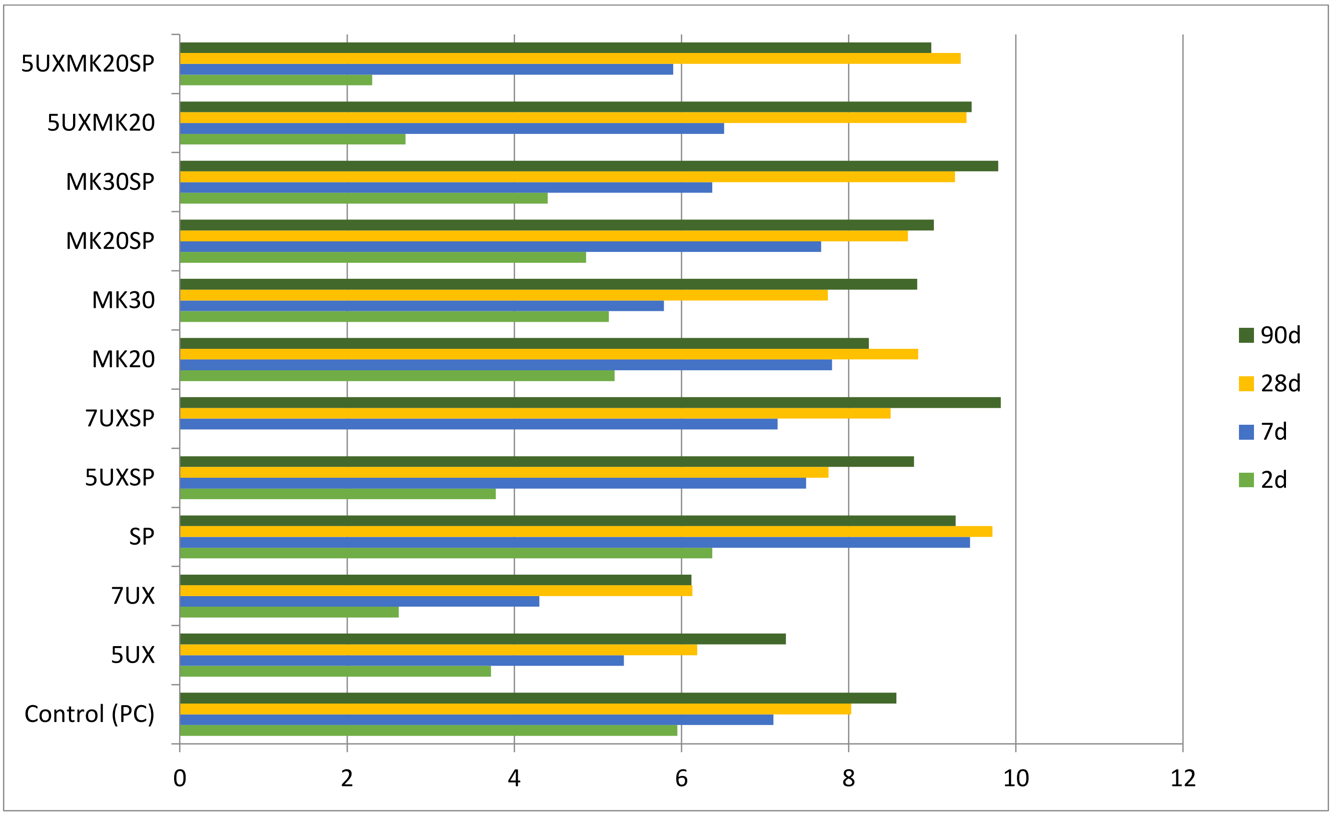

Figure 2. Comparison of flexural strength values as per 2nd, seventh, 28th and 90th days

3.5. Unit Weight

All samples' unit weights were measured. The results were presented on Table 11. According to the obtained results, 5UX-MK20 had the lightest unit weight with 2.295 g/cm^3 (3.81% higher than PC), and 7UX had the heaviest unit weight with 2.437 g/cm^3 (2.14% heavier than PC). The slight reduction in the densities of MK and UX samples was due to the changing specific gravity of MK and UX compared to cement alone.

Table 12. Unit weight test results

Sample name	Unit weight (g/cm^3)
Control	2.386
5UX	2.392
7UX	2.437
SP	2.428
5UX-SP	2.393
7UX-SP	2.396
MK20	2.367
MK30	2.309
MK20-SP	2.360
MK30-SP	2.302
5UX-MK20	2.289
5UX-MK20-SP	2.295

3.6. Water Absorption

A water absorption test WAS conducted for all 12 samples, and the change between wet and dry weights was presented on Table 12. According to the test, 7UX had the highest water absorption capacity (7.892%), and MK30-SP (3.419%) had the lowest absorption capacity, respectively.

UX has more water absorption capacity when it's compared to MK, and SP reduces water absorption via water demand reducer chemicals. It was seen that increasing water absorption leads to negative effects in terms of durability when the compressive and flexural strengths and water absorption capacity are assessed together.

Table 13. Water absorption test results

Sample name	Water absorption (%)
Control	**6.524**
5UX	**7.508**
7UX	**8.892**
SP	**5.161**
5UX-SP	**5.701**
7UX-SP	**5.253**
MK20	**6.237**
MK30	**5.846**
MK20-SP	**4.942**
MK30-SP	**3.419**
5UX-MK20	**5.691**
5UX-MK20-SP	**5.507**

3.7. Porosity

The results of the porosity test conducted are shown in Table 13. The given percentages represent the ratio between dry weight, wet weight and Archimedes' weight. The porosity results were provided on Table 13.

Only the samples including the replacement of only 5% and 7% of ulexite gave higher results compared to the control sample. Other samples gave higher porosity results. It can be concluded that ulexite increases and metakaolin decrease the porosity of the cement. Additionally, adding SP decreases porosity.

Table 14. Porosity test results (%)

Sample name	Porosity
Control (PC)	13.425
5UX	15.231
7UX	16.129
SP	11.143
5UX-SP	12.110
7UX-SP	11.189
MK20	12.831
MK30	11.865
MK20-SP	11.572
MK30-SP	7.314
5UX-MK20	11.952
5UX-MK20-SP	11.228

3.8. Effect of Water/Cement Ratio

In order to estimate the required amount of water, sample series were prepared and in these series water/cement (W/C) ratio changed between 0.4 and 0.6. The W/C ratio was increased in some samples due to hard mixing and compaction.

In this study, three types of W/C ratios were used. These were 0.6 (high), 0.5 (average) and low (0.4), which are more typically used. High W/C ratio for MK30. average W/C ratio for the samples control (PC), 5UX, 7UX, MK20, MK20-SP, MK30-SP, 5UX-MK20 and 5UX-MK20-SP in acceptable margins. Furthermore, due to their extreme fluidity, for the samples, SP, 5UX-SP and 7UX-SP low W/C ratio was used.

Table 15. W/C ratios of the samples

Sample name	W/C ratio
Control (PC)	0.5
5UX	0.5
7UX	0.5
SP	0.4
5UX-SP	0.4
7UX-SP	0.4
MK20	0.5
MK30	0.6
MK20-SP	0.5
MK30-SP	0.5
5UX-MK20	0.5
5UX-MK20-SP	0.5

The samples with the low W/C ratio had the best results. However, the compressive and flexural strength results showed that the W/C ratio data are not sufficient to determine the effect of the W/C ratio on durability. To conclude, the W/C ratios of the samples should be increased and all three ratios should be used for every sample.

4. Conclusion

The flow table test showed that blending only ulexite in 5% and 7% proportions decreased the workability of the fresh mortars. However, the inclusion of Polydos® TS 14 superplasticizer solves this problem and increases the workability. Likewise, mixes containing MK only in 20% and 30% showed low workability, and the problem was solved by adding Polydos® TS 14 superplasticizer.

The addition of ulexite only prolonged the mortar's setting time. The addition of only 5% of ulexite extended the setting time to 2.97 hours, and the addition of only 7% of ulexite extended 6.40 hours. The addition of Polydos® TS 14 superplasticizer to the 5% and 7% ulexite-only samples extended the setting time to 5.74 hours and 12.75 hours, respectively. It might be caused due to increasing percentage of %B_2O_3 with ulexite. It is known that a high concentration of %B_2O_3 causes retarding in setting time and decreasing in compressive strength.

MK facilitates early hardening depending on the W/C ratio. Using MK only in 20% and 30% proportion helps mortar gain flexural strength close to the control sample's value. However, adding 20% MK helps the mortar gain higher compressive strength than the control sample. Also, the addition of Polydos® TS 14 superplasticizer helps the mortars to improve their strength results.

An increase in the amount of ulexite leads to a proportional increase in unit weight, porosity and water absorption characteristics.

Adding a superplasticizer decreases the porosity of the hardened mortars. It is shown that, with the decrease in porosity, the durability of the cement increases.

Water absorption also decreases with the addition of a superplasticizer. It is shown that the more water absorption in the samples gives the less durability. They have inverse proportions. Furthermore, the water absorption results are not a reliable parameter for concrete durability estimation.

In conclusion, UX should not be used in mortar only. If it will be used, an additional chemical such as Polydos® TS 14 superplasticizer could be used. The superplasticizer amount cannot exceed 1% in providing a mixture within a reasonable time. Also, additional compounds such as MK should be used with UX. The percentage of MK should not exceed 30%. If it will be higher than that, the W/C ratio should also be increased. Otherwise, flocculation will increase and workability will decrease. In the literature, the replacement of MK by 30% gives promising results. This supports our study. However, due to the large gap in the amount of MK in this study, further studies should be carried out on a more detailed assessment. An additional study may be carried out to include the other experiments such as freezing-thawing, acid and sulphate attacks, alkali-silica reaction tests and hydration heat measurements which were not included in this study.

Moreover, since there is not sufficient data on UX replacement in cement, further studies should be conducted in order to obtain more detailed information.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1]. Australian Government Department of Agriculture, Water and the Environment. Boron and compounds. Available from: http://www.npi.gov.au/resource/boron-and-compounds (Accessed: 30.01.2022)

[2]. Meydan, E. Boron compounds with magnetic properties and their application areas in the industry. Journal of scientific perspectives. 3 (2019) 11-20.

[3]. Gezmen, T, Türkel, S. Bor minerali ve uçucu kül içeren harçların mekanik özelliklerinin ve sülfata dayanıklılığının incelenmesi. Dokuz Eylul University-Faculty of Engineering Journal of Science and Engineering. 19 (2017). DOI: 10.21205/deufmd.2017195768

[4]. Industrial Minerals Association North America. What are borates. Available from: https://www.ima-na.org/ (Accessed: 02.02.2022)

[5]. Werheit H., Filipov V., Kuhlmann U., Schwarz U., Armbrüster M., Leithe-Jasper A., Tanaka T., Higashi I., Lundström T., Gurin V.N. Raman effect in icosahedral boron rich solids, Science and Technology of Advanced Materials 11 (2010) 1-27.

[6]. Eti Maden. Boron minerals. Available from: https://www.etimaden.gov.tr/en/boron-minerals (Accessed: 02.02.2022)

[7]. Davraz, M. The effects of boron compounds on the properties of cementitious. composites. Special issue of the International Conference on Computational and Experimental Science and Engineering (ICCESEN 2014). 128 (2015). DOI: 10.12693/APhysPolA.128.B-26

[8]. Pehlivanoğlu, H.C., Davraz, M., Kılınçarslan, Ş. Bor bileşiklerinin çimento priz süresine etkisi ve denetlenebilirliği. SDU International Technologic Science. 5 (2013) 39-48.

[9]. ÇİMSA. Mineral katkılar-metakaolin. Available from: https://www.cimsa.com.tr/ca/docs/4FE58AA58E3A4B7B85FA9E4EE011A8/2F1F16CC23ED4D44AF2BAE31D85C1A94.pdf (Accessed 02.02.2022)

[10]. Rasekh, H, Joshaghani, A, Jahandari, S, Aslani, F, Ghodrat, M. In: Self-Compacting Concrete: Materials, Properties and Applications, 2020, Woodhead Publishing

Series in Civil and Structural Engineering. (2020) 31-63 DOI: doi.org/10.1016/B978-0-12-817369-5.00002-7

[11]. Glavind, M. In: Sustainability of Construction Materials. Sustainability of cement, concrete and cement replacement materials in construction. (2009) DOI: 10.1533/9781845695842.120

[12]. Yazıcı, Ş, Anuk, D, Arel, H.Ş. Metakaolin kullaniminin harçlarin mekanik özellikleri üzerine etkisi. J Fac Eng Arch Selcuk Univ 25 (2010). 2.

[13]. Ashik, M.M., Gomathi, D. Strength properties of concrete using metakaolin. International Journal of Engineering Research & Technology (IJERT). 6 (2017). DOI: 10.17577/IJERTV6IS110063

[14]. Park, K.B, Lin, R.S., Han, Y, Wang, X.Y. Model-based methods to produce greener metakaolin composite concrete. Composite Concrete. Applied Scienes 11 (2021,) DOI: 10.3390/ app112210704

[15]. Uğurlu, A, Özdemir, M, Topçu, İ. Bor içeren kil atıkların çimento içerisinde değerlendirilmesi - evaluation of boron containing clay wastes in cement [Article in Turkish]. Uluslararası Bor Sempozyumu, 23-25 Eylül 2004 Eskişehir Türkiye

[16]. Demirel, B, Nasıroğlu, S. Bor mineralleri ve atıklarının çimentoda kullanılma stratejileri [Article in Turkish]. Science and Engineering Journal of Fırat University 29 (2017) 95-100.

[17]. Targan, Ş., Erdoğan, Y., Olgun, A. Kula Cürufu, Bentonit ve Kolemanit Atıklarının Termik Çimento Üretiminde Değerlendirilmesi", 1. Uluslararası Bor Sempozyumu, Kütahya, (2002) 259-266.

[18]. Anuk, D. Metakaolin kullanımının çimento harçlarının mekanik ve durabilite özelliklerine etkisi / Effect of metakaolin on the mechanical and durability properties of cement mortars. Master's Thesis, 2011, İzmir.

[19]. Yenialaca, Ç. Bor ve kullanım alanları. Master's Thesis. Gazi Universitesi. 2009, Ankara.

[20]. General Directorate of Mineral Research and Exploration of Turkey. Üleksit. Available from: https://www.mta.gov.tr/v3.0/bilgi-merkezi/uleksit (Accessed: 12.04.2022)

[21]. Eti Maden. Ulexite. Available from: https://www.etimaden.gov.tr/en/ulexite (Accessed: 12.04.2022)

[22]. Canımkurbey, B. Electrical properties of ulexite by dielectric spectroscopy. Erzincan University Journal of Science and Technology. 13 (2020) 88-94.

[23]. Piotrowski, T, Glinicka, J, Glinicki, M.A., Prochoń, P. Influence of gadolinium oxide and ulexite on cement hydration and technical properties of mortars for neutron radiation shielding purposes. Construction and Building Materials 195 (2019) 583-589.

[24]. Ucar, N, Calik, A, Emre, M, Akkurt, I. Physical-radiation shielding properties of concrete contains colemanite and ulexite. Indoor and Built Environment 30 (2021) 1420326X2096797. DOI: 10.1177/1420326X 20967974

[25]. Lin, Wei-Ting, Cheng, An. Effect of metakaolin on strength and efflorescence quantity of cement-based composites. The Scientific World Journal. DOI: 10.1155/2013/606524