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Research Article

EFFECT OF DIFFERENT PERMEABILITY REDUCING ADMIXTURE ON FLOWABILITY PERFORMANCE OF DIFFERENT TYPE OF MINERAL ADMIXTURE-CONTAINING MORTAR MIXTURES

Ali NEMATZADEH[1], Ece GEVEN[2], Süleyman ÖZEN[3], Metin İLHAN[4], Ali MARDANI AGHABAGLOU*[5]

[1]*Uludag University, Department of Civil Engineering, BURSA;* ORCID: 0000-0002-9065-7449
[2]*Uludag University, Department of Civil Engineering, BURSA;* ORCID: 0000-0001-5490-0205
[3]*Uludag University, Department of Civil Engineering, BURSA;* ORCID: 0000-0001-5522-427X
[4]*Uludag University, Department of Civil Engineering, BURSA;* ORCID: 0000-0002-0646-1786
[5]*Uludag University, Department of Civil Engineering, BURSA;* ORCID: 0000-0003-0326-5015

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ABSTRACT

In this study, the effect of different permeability-reducing admixtures on the flowability performance of cement paste mixtures containing different ratios of mineral admixtures was investigated. For this purpose, the cement paste and mortar mixtures having plain, binary and ternary binder systems were prepared by partial replacement of cement with fly ash and metakaolin. Besides, the compressive strength of the mortar mixture was measured at different ages. In order to investigate the effect of utilization of permeability-reducing admixture on properties of the cementitious systems, 3 commercial permeability-reducing admixtures which produced by 2 different companies were used as 2 wt.% of cement. Three series of mineral admixture-containing mixture was prepared. In the first and second series, 10% and 20% of the cement were replaced with fly ash and metakaolin, respectively. In the third series, mixtures having ternary binder systems were produced by replacing of 10% and 20% of cement with fly ash and metakaolin, respectively. Consequently, 23 different cement paste and mortar mixtures were prepared in the scope of the study. According to the test results, it was unexpected, in spite of increase of the total amount of fine materials by utilization of metakaolin instead of cement in the mixture, the flowability of mixtures was positively affected, in the case of presence of sufficient amount of water-reducing admixture in the system. This mentioned positively effect may be attributed to the fact that the water-reducing admixture is more easily adsorbed on the finer grains.
Keywords: Mineral admixture, water reducing admixture, permeability reducing admixture.

1. INTRODUCTION

The concrete property which it stayed unaffected from the exposed negative factors and keeps its strengths and qualifications for years is called as durability [1]. These effects are classified as external and internal effects based on physical, chemical, biological or mechanical effects. Sulphate effect, freeze-thaw, abrasion, acid-base, and salt effects can be considered as the external effects. Alkali-aggregate reaction, differences between the thermal properties of aggregate and

* Corresponding Author: e-mail: ali.mardani16@gmail.com, tel: (224) 294 27 93

cement paste can be considered as the internal effects [2]. As it is known fact that the concrete strength against sulphate, acid, carbonation, reinforcement corrosion, freeze-thaw, and alkali-silica reaction is related to the permeability performance of the concrete [3, 4]. Thus, permeability and diffusivity coefficient are among the most important factors affecting the durability of the concrete structure considerably [3, 5]. Concrete permeability might evolve related to the capillary pore volume of the concrete at the internal structure, and the connection between those pores. Min eral and chemical admixtures can be used in the mixtures in order to reduce the concrete permeability against the mentioned harmful effects [3].

Harmful gases emitted into the air as a result of the cement production consist of 2.5% of the gases emitted from all industrial sources throughout the world. One of the effective ways to reduce this environmental effect is to use pozzolanic mineral admixture replacing with cement [6]. Waste and binding assistive materials such as fly ash, blast furnace slag, silica fume, rice husk ash and metakaolin are commonly used by replacing with portland cement in order to enhance mechanical and durability properties of the cementitious systems.

It is a known fact that mineral admixture use in cementitious systems increases the strength and durability of the cementitious systems due to the physicochemical impacts created. Since the mineral admixtures are finer in terms of physical structure, a less porous structure occurs by blocking the pores of the cement systems. On the other hand, in terms of chemical structure, it turns calcium hydroxides (CH) into calcium silica hydrates (CSH) with stronger structures and providing binding properties to the cement systems, as a result of the pozzolanic reaction. Fineness, amorphism level and chemical compound of the mineral admixtures affect the pozzolanic reaction considerably. Therefore, pozzolanic reaction occurs at early ages when the mineral admixtures are finer as well as higher reactive silica is included [7].

Since the grain sizes of the admixtures used in concrete mixtures are considerably fine and show pozzolanic reaction, impermeability performance of the concrete can be increased by reducing capillary pores and improving aggregate-paste interfacial transition zone when they are used instead of cement or as filler in the concrete [8-9].

Within the last 20 years, above-mentioned admixtures are commonly used in order to develop the concrete durability as well as water impermeability. Permeability reducing admixtures might be considered as alternative for membrane-based waterproofing systems when they are used during the implementation. According to ACI 212.3R.162 permeability-reducing admixtures are classified into two main groups. First, is the permeability reducing admixtures for hydrostatic conditions (water tanks, underground car parks) and the second is the permeability reducing admixtures for non-hydrostatic conditions (at roof slabs and precast panels). Concrete might barely or never be exposed to pressure water under non-hydrostatic conditions (at roof slabs and precast panels). Water, at this stage, might enter into concrete through capillary absorption method. It is highly possible that the concrete is exposed to hydrostatic pressure water substantially under hydrostatic conditions and when permeability is significant (water tanks, underground car parks) [10]. Different types of materials are used with regard to those conditions as permeability-reducing admixture.

Crystalline products are used as permeability reducing admixtures for hydrostatic conditions (PRAH) and permeability-reducing admixtures for non-hydrostatic conditions [11].

Chemicals of the hydrophilic crystalline structures increase C-S-H gel density by reacting with cement and water as well as showing the effect as pore blocker. Thus, they decrease the effective porosity in paste and aggregate-paste interface. Those admixtures contain water repellent chemicals including various oils and long chain fatty acids. Walls of the voids create a thin layer and perform as water repellent [11].

Today liquid or pulverized permeability-reducing chemical admixtures with different mechanisms from mineral admixtures are produced along with the development of concrete technology. A part of those admixtures (permeability reducing admixtures) are added into the concrete when they are fresh and provide impermeability for the concrete by blocking the capillary pores. The other part of tho se admixtures (humidity preventive admixtures) can be added into the concrete as applied to its surface. Those admixtures provide impermeability by enabling concrete to be water-repellent [12].

Some studies regarding the use of mineral and permeability-reducing admixtures in concrete mixtures are summarized below.

Dinçer et. al [13] investigated the effect of using fly ash instead of different amounts of cement on mechanic properties of concrete mixtures. Within this aim, five different amounts of fly ashes between 0% and 40% of cement by weight were replaced to concrete mixtures. According to the test results, fly ash use as 30% instead of cement affected mechanical properties of the concrete mixtures positively. It is observed that the most successful results were obtained from 20% fly ash replacement.

Mardani-Aghabaglou et. al. [14] investigated the effect of using fly ash, silica fume, and metakaolin use instead of cement on compressive strength, dynamic elasticity module, chlorine ion permeability, water absorption, capillary absorption, freeze-thaw and sulphate resistance comparatively. Moreover, microstructure analysis was realized on certain mixtures. Regression analysis was performed on test results of the sulphate resistance. Authors stated that the existence of various types of mineral admixture in mortar mixtures changes the ettringite morphology. Ball type, and a special type of ettringite formation were observed in the mixtures including silica fume and metakaolin, respectively. Needle type and ball type ettringites were formed in the mixtures including fly ash. In the control mixture, on the other hand, needle type, ball type, and massive type ettringite formations were determined. According to the test results, the mixtures are aligned as the ones with silica fume, metakaolin, fly ash and the control mixture, respectively.

According to the research by Jamal et. al. [15] entitled water absorption characteristics of concrete mixtures including metakaolin, adding partial metakaolin (MK) instead of cement due to its high pozzolanic activity improved durable and mechanical properties of concrete. Besides, adding MK into the concrete instead of cement reduced water intake through the capillary method.

Hassani et. al [11] investigated the efficiencies of the hydrophobic water repellents and crystalline pore blockers in concrete mixtures by using fly ash with fixed w/c rate and portland cement including high furnace slag. According to the results, w/c ratio and the effect of cementitious system changes on concrete mixture properties was more pronounced compared to those of permeability-reducing admixtures. Hydrophobic water repellents and crystal pore blockers were beneficial in terms of reducing water absorption ratio in concrete samples (under both hydrostatic and non-hydrostatic conditions). Water treatment depth of the mixtures decreasing 45% with the addition of HP admixture (hydrophobic water-repellent admixture) into concrete mixtures can be given an example. It was also found out that admixtures are more effective in concrete mixtures with 0.4-0.6 w/c ratio [16].

Baradan et. al [17] observed the effect of water impermeability admixture use on certain properties of the concrete mixtures. For this, two different admixtures as lignosulfonate based (LS) modified the production of the same company as well as the WRC consisting of modified lignosulfonate and organic fatty acid ester are used. During the first stage of the study, permeability and strength parameters of the mortar mixtures including water impermeability admixture with different amounts were investigated. During the second stage, on the other hand, pressurized water treatment depth was measured in concrete mixtures prepared by using WRC admixture as 0%, 3%, and 5%. According to the results, in terms of reducing the permeability of WRC type admixture concrete mixtures showed better performance than that of the LS admixture. With this regard, the mixture with 5% WRC showed better performance than those of the others in terms of water absorption ratio.

In a study by Akyol [18], determination of the parameters affecting the permeability of concrete mixtures and investigation of effective mechanisms was purposed. PC 42.5 cement was used a binder in the mixtures. Cement ratio was stable and 320 kg/m^3. 5 different concrete mixtures were produced in total in addition to the control mixtures constituting impermeability admixture as 0.5%, 1%, 1.5% and 2% of cement weight. Results show that water requirement increased in order to provide the same workability in the mixtures including different amounts of impermeability admixture. Minimum water requirement was obtained with the impermeability admixture used as 2%. Maximum compressive strength was observed in the mixture including 2% impermeability admixture. This behavior can be explained as the water/cement ratio was less in relation to lower water requirement in the mixtures with 2% admixture. The maximum weight per unit of volume was obtained from the control mixture. The reason why the weight per unit of volume of the concrete mixtures with impermeability admixture is emphasized as the admixture show its air-entrainment feature. It is also stated that another reason for this situation is the increasing w/c ratio in accordance with the reduction of water requirement in order to provide the same slump value by using water impermeability admixture.

As can be understood from the literature that many kinds of researches were conducted in the field of mineral admixture use. Mineral admixtures are mostly replaced as binary cementitious systems instead of cement. Moreover, there are some researches on the effects of the permeability-reducing admixture use on cementitious system properties. However, there are scarce studies about the joint use of the mineral and permeability reducing admixtures in cementitious systems. In this study, fly ash and metakaolin are used instead of cement by creating dual and ternary cementitious systems. Moreover, the influence of the mineral admixture use along with the permeability admixture on certain properties of the paste and mortar mixtures were investigated. Marsh-funnel flow time, as well as mini-slump tests, were conducted in order to examine the compatibility of the used admixtures with cement. 28 and 90-day compressive strengths were compared in mortar mixtures.

2. EXPERIMENTAL STUDIES

2.1. Materials

In this study, CEM I 42.5 R type portland cement in accordance with TS EN 197-1 [19] Standard was used as a binder as well as fly ash and metakaolin were used as a mineral admixture. Chemical compound and physical properties of the cement, fly ash and metakaolin provided by the manufacturer are shown in Table 1 and 2, respectively. CEN standard sand in accordance with TS EN 196-1 [20] was used as aggregate. Grain size distribution of the standard sand is shown in Table 3. Moreover, specific gravity and water absorption capacity of the aggregate was obtained as 2.72 and 0.7% by weight in accordance with TS EN 1097-6 [21].

Table 1. Chemical composition and mechanical and physical properties of cement.

Item	(%)	Physical properties		
SiO_2	18.86	Specific gravity		3.15
Al_2O_3	5.71	**Mechanical properties**		
Fe_2O_3	3.09	Compressive strength (MPa)	1-day	14.7
CaO	62.70		2-day	26.80
MgO	1.16		7-day	49.80
SO_3	2.39		28-day	58.5
Na_2O+0.658 K_2O	0.92	**Fineness**		
Cl^-	0.01	Blaine specific surface (cm^2/g)		3530
Insoluble residual	0.32	Residual on 0.045 mm sieve (%)		7.6
Loss on ignition	3.20			
Free CaO	1.26			

Table 2. Chemical composition and physical properties of fly ash and metakaolin.

	F*	M**		F*	M**
Item	**(%)**		**Physical properties**		
SiO_2	59.22	56.10	Specific gravity	2.31	2.52
Al_2O_3	22.86	40.23	Blaine specific surface (cm^2/g)	4300	146000
Fe_2O_3	6.31	0.85			
$SiO_2 + Al_2O_3 + Fe_2O_3$	88.39	0.00	**Pozzolanic Activity Index**		
MgO	1.31	0.16	7-day (%)	70.9	98.03
Na_2O	0.41	0.24	28-day(%)	77.7	104.50
K_2O	1.51	0.51	90-day (%)	91.2	110.21
SO_3	0.17	0.00			
CaO	3.09	0.19			
Free CaO	1.26	0.00			

*Fly ash, **Metakaolin

Table 3. Particle size distributions of standard sand.

Sieve size (mm)	Retained (%)	Cumulative sieve residue (%)
2.00	0	0
1.60	4.32	7 ± 5
1.00	33.98	33 ± 5
0.50	67.11	67 ± 5
0.16	86.85	87 ± 5
0.08	99.83	99 ± 5

In order to investigate the effect of permeability-reducing admixtures (PRA) in the mortar and paste mixtures 3 PRAs were obtained as commercial products of 2 different companies. In the mixtures with PRA, used admixture amount was stabilized as 2% by cement weight. Some properties of the used admixtures provided by the manufacturer are shown in Table 4. Besides, a type polycarboxylate based high range water reducing admixture was used in paste and mortar mixtures and their properties are shown in Table 5.

Table 4. Some properties of permeability reducing admixture provided by the manufacturer.

No	**Type**	**Density (gr/cm^3)**	**Solid Content (%)**	**PH Value**	**Chloride Content (%)**	**Alkali Content (%) (Na_2O)**	**Chemical Admixture Usage Range (%)**
PRA1	Liquid	1.115	21.85	9.02	0.015	0.320	0.8-3.0
PRA2	Liquid	1.095	12.45	10.30	0.025	0.250	0.8-3.0
PRA3	Liquid	1.04	8	9.72	<0.1	< 0.5	0.8-3.0

Table 5. Properties of polycarboxylate-ether based high range water reducing admixture.

Colour	**Density (gr/cm^3)**	**Solid Content (%)**	**pH Value**	**Chloride Content (%)**	**Alkali Content (Na_2O) (%)**
Brown	1.097	36.35	3.82	<0.1	<10

2.2. Testing Procedures

Preparation of Cement Paste Mixtures

Considering the previous studies, w/c ratio of the paste mixtures were determined as 0.35 for Marsh-funnel and mini-slump tests [22]. 3 different mixtures (K-KU-KM-KUM) containing mineral admixtures were produced in addition to the control mixture without mineral admixture and reducing permeability. Thereafter, 12 different mixtures were prepared by using 3 different permeability-reducing admixtures as 2% of cement by weight in these produced 4 mixtures. Mixtures containing PRA are named in terms of used permeability-reducing admixture name. For instance, control paste mixture including 2% PRA1 is represented as “K-PRA1”. Naming both mineral and permeability including mixtures, for example, are designated as "KU-PRA1" the mixture with fly ash and 2% PRA1 by cement. Material amount and designation of the mixtures are shown in Table 6.

Table 6. Material quantity (g) by weight used in the production of cement paste and flow value (mm).

Paste Mixture	Cement	Fly Ash	Metakaolin	Water	W/C	PRA*	SP**	Mini Slump (mm)
K	700	0	0	245	0.35	0	3.5	167.5
KU	560	140	0	245	0.35	0	3.5	205
KM	630	0	70	245	0.35	0	3.5	157.5
KUM	490	140	70	245	0.35	0	3.5	100
K-PRA1	700	0	0	245	0.35	14	3.5	110
KU-PRA1	560	140	0	245	0.35	14	3.5	120
KM-PRA1	630	0	70	245	0.35	14	3.5	130
KUM-PRA1	490	140	70	245	0.35	14	3.5	107.5
K-PRA2	700	0	0	245	0.35	14	3.5	125
KU-PRA2	560	140	0	245	0.35	14	3.5	120
KM-PRA2	630	0	70	245	0.35	14	3.5	90
KUM-PRA2	490	140	70	245	0.35	14	3.5	100
K-PRA3	700	0	0	245	0.35	14	3.5	157.5
KU-PRA3	560	140	0	245	0.35	14	3.5	90
KM-PRA3	630	0	70	245	0.35	14	3.5	80
KUM-PRA3	490	140	70	245	0.35	14	3.5	95

***** Permeability Reducing Admixture, ****** Super plasticizer

For each 16 paste mixtures, in addition to the mixture without water reducing admixture, 6 and 7 paste mixtures were prepared by utilization of different amounts of water reducing admixtures ranging between 0.5-2 wt.% of cement. Marsh-funnel flow time and mini-slump tests were performed on prepared paste mixtures.

Preparation of the Mortar Mixtures

Mortar mixtures were prepared in accordance with ASTM C109 [23]. In addition to the control mixture (K) without mineral and permeability reducing admixture, 6 more mortar mixtures were prepared by using mineral and permeability-reducing admixtures. In the mixtures including mineral admixture, 20% fly ash (KU) and 10% metakaolin (KM) were used instead of cement, in the first and second series, respectively. In the third series, on the other hand, 10% and 20% fly ash and metakaolin were replaced by cement weight and the mortar mixtures named as KUM were prepared with a ternary cementitious system. Mortar mixtures including 3 different permeability reducers as 2% by cement weight were produced. For all mixtures, water/binder and sand/binder ratios, as well as flow values were kept constant as 0.485, 2.75 and 270 ± 20 mm, respectively. As emphasized before, in order to provide the desired flow value, a type of polycarboxylate based high range water reducing admixture was used. Mixtures are prepared in Hobart Mixer homogeneously. Mixture ratios are shown in Table 7.

Table 7. Material quantity (g) by weight used in the production of mortar mixture and flow value (mm).

Mixture	Cement	Fly Ash	Metakaolin	Water	Sand	PRA *	SP**	Flow Value (mm)
K	500	0	0	242.5	1375	0	2.50	265
KU	400	100	0	242.5	1375	0	1.50	257
KM	450	0	50	242.5	1375	0	2.85	257
KUM	350	100	50	242.5	1375	0	2.75	265
PRA1	500	0	0	242.5	1375	10	1.00	280
PRA2	500	0	0	242.5	1375	10	1.50	262
PRA3	500	0	0	242.5	1375	10	2.50	250

***** Permeability Reducing Admixture, ****** Superplasticizer

3. TEST RESULTS AND DISCUSSION

3.1. Fresh State Properties

Marsh-Funnel Flow Time and Mini-Slump

Marsh-Funnel flow times, mini-slump values and temperatures of the paste mixtures containing mineral admixture are shown in Table 8 and Figure 1. Since the paste mixtures including less water reducing admixture than 0.5% of cement by weight were unable to flow from the Marsh-funnel, it was not possible to measure the flow time of those mixtures. As can be seen from the results that flow times of the paste mixtures reduced as expected with the increase of water reducing admixture use apart from the type of the mineral admixture. Marsh-funnel flow times increased compared to the control mixture when water reducing admixture was used as 0.5% by cement weight in the paste mixtures including mineral admixture. Initial flow times of “KU” and “KM” mixtures were 43% and 95% more than that of the control mixture, respectively. When 0.5% of water reducing admixture was used in “KUM” mixture, it did not flow from Marsh-funnel. “K” mixture showed the minimum performance compared to the other mixtures in terms of Marsh-funnel flow time.

“KUM” and “KM” mixtures showed similar behaviours since 1% admixture amount in terms of Marsh-funnel flow time. According to Mardani-Aghabaglou et. al, (24) flow performances of the mixtures are affected positively in contrast to the expected with the increase of binder fineness provided there is enough water reducing admixture in the cementitious systems. Authors state that this is due to the fact that water-reducing admixture is absorbed more easily on finer grains. Similar results were observed in this study. Mixtures containing metakaolin with a fineness of about 40 times higher than the cement used showed a lower performance compared to the control mixture for flow performance up to 1% of water-reducing admixture content. However, metakaolin including mixtures demonstrated lower performance in comparison with the control mixture in terms of flow performance up to 1% water reducing admixture content when water-reducing admixture above that amount was added. Nevertheless, the addition of water reducing admixture at higher amount metakaolin including admixtures showed better flow performance. Regardless of mineral admixture type and content, the saturation point was determined when water reducing admixture-cement ratio is 1% for all cement-admixture couples.

Regarding flow times at saturation point, "KM" and "KUM" mixtures flowed from the Marsh-funnel 11% and 7% quicker than that of control mixture, respectively. However, only "KU" mixture, which includes only fly ash as a mineral admixture, showed 17% slower flow performance than the control mixture. It is considered that the viscosity of the paste mixtures with 1% or more water reducing admixture reduced only with the addition of metakaolin or fly ash and metakaolin together as well as increased with the addition of only fly ash. Within this regard, the increase of viscosity upgraded Marsh-funnel flow times, the decrease of viscosity declined the flow time.

Increase in mini-slump values of the paste mixtures was observed as expected with the increase of water reducing admixture use independently from mineral admixture type. However, stabilization or reduction in the mini-slump values for the paste mixtures over a specific amount of admixture use were also observed. It is thought that this situation has resulted from segregation of mentioned mixtures regarded as considerably flowable. Moreover, mixture temperatures reduced between 2-3°C with increasing water reducing admixture content in all cement pastes. It is regarded to be resulted from the retarding effect of the water-reducing admixture.

Table 8. Marsh-funnel flow time, mini-slump and temperature values of cement paste mixtures in the absence and presence of mineral admixture.

Admixture/cement rate (by weight %)		**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**
Flow time, sec	**K**	131.4	87	76.8	76.2	76.2	76
	KU	188.4	127.8	90	84	85.2	85.8
	KM	256.8	75	68.4	61.8	61.2	61.2
	KUM	-	206	72	63	57	57
Temperature, °C	**K**	27	26.8	25.6	25	23	24
	KU	25.5	25.2	25	25	24.5	23.5
	KM	25.5	25.2	25	25	24.5	23.5
	KUM	30.7	30	28.4	28.1	28	27.7
Mini slump, mm	**K**	167.5	192.5	200	200	212.5	220
	KU	205	217.5	212.5	217.5	215	225
	KM	157.5	202.5	180	187.5	192.5	192.5
	KUM	-	110	145	157.5	155	155

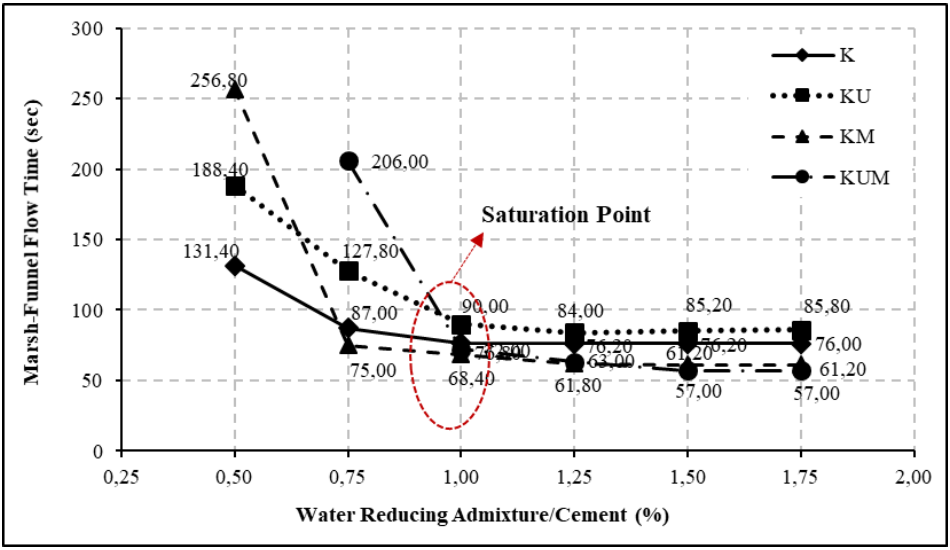

Figure 1. Marsh-funnel flow time of cement pastes containing mineral admixture.

Marsh-funnel flow times, mini-slump and temperature values of the paste mixtures containing control mineral, as well as "PRA1" permeability reducing admixture, are shown in Table 9 and Figure 2. When "PRA1" admixture was added to the mixtures, significant reductions in terms of initial Marsh-funnel flow times compared to the mixtures without permeability reducing admixture were realized in general. Besides, saturation points of "K-PRA1", "KU-PRA1" and "KM-PRA1" mixtures were realized in lower water reducing admixture/cement ratio (0.75%) compared to the "K", "KU" and "KM" mixtures without "PRA1". PRA1 admixture showed a fair amount of plasticizer effect in those mixtures and the water reducing admixture reduced the saturation point up to 0.25%. It is considered that this positive effect occurred as a result of the decreasing viscosity of the mixtures with the addition of "PRA1" admixture into the mixtures. As emphasized before, according to the manufacturer, "PRA1" admixture reduces permeability by means of air-entrainment. Within this context, "PRA1" admixture showed viscosity reducing the effect by entraining air bubbles to the mixture. Nevertheless, flow performance of the mixture was affected negatively compared to that of "KUM" mixture with the same water reducing admixture amount when higher than 0.75% water reducing admixture was added into the KUM-PRA1 mixture. Moreover, the saturation point of the "KUM" mixture was determined where water reducing admixture/cement amount was 1.5%. 72% reduction in Marsh-funnel flow performance of the "KUM-PRA1" mixture was observed when the water reducing admixture ratio was 1.5%. It is stated that the negative result was caused by the increasing viscosity values due to the fact that the use of "PRA1" brought incompatibility in the mixture where fly ash and metakaolin are used together. Apart from mineral admixture type, an expected increase in mini-slump values of the paste mixtures was observed in the mixtures including "PRA1" admixture. However, the addition of PRA1 admixture into the "K", "KU", "KM" and "KUM" mixtures affected mini-slump values of the mixtures negatively. Mini-slump values of the "K-PRA1" and "KU-PRA1" mixtures reduced between 35-40% while "KM-PRA1" between 20-30% and "KUM-PRA1" mixture around 10% depending upon water reducing admixture amount. This negative effect is thought to be resulted from increasing yield stress of the mixtures with "PRA1".

Table 9. Marsh-funnel flow time, mini-slump and the temperature value of cement paste mixtures containing both mineral admixture and PRA1.

Admixture/cement rate (by weight %)		**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2**
Flow time. sec	**K-PRA1**	72	65	63	62	60	60	62
	KU-PRA1	165	107	96	91	91	92	94
	KM-PRA1	75	62	56	54	50	48	49
	KUM-PRA1	280	135	116	106	98	97	100
Temperature. °C	**K-PRA1**	32.7	32.1	32	32.4	32.2	32.2	32
	KU-PRA1	32.2	32.8	31.3	30.3	30	30.5	30
	KM-PRA1	31	27.8	27.5	27.3	29.2	30.2	29.5
	KUM-PRA1	30.6	31.2	30.3	32.2	31.8	32.2	31
Mini slump. mm	**K-PRA1**	110	120	122.5	127.5	127.5	135	140
	KU-PRA1	120	127.5	135	140	140	140	140
	KM-PRA1	130	137.5	140	145	145	145	155
	KUM-PRA1	107.5	122.5	132.5	140	145	145	145

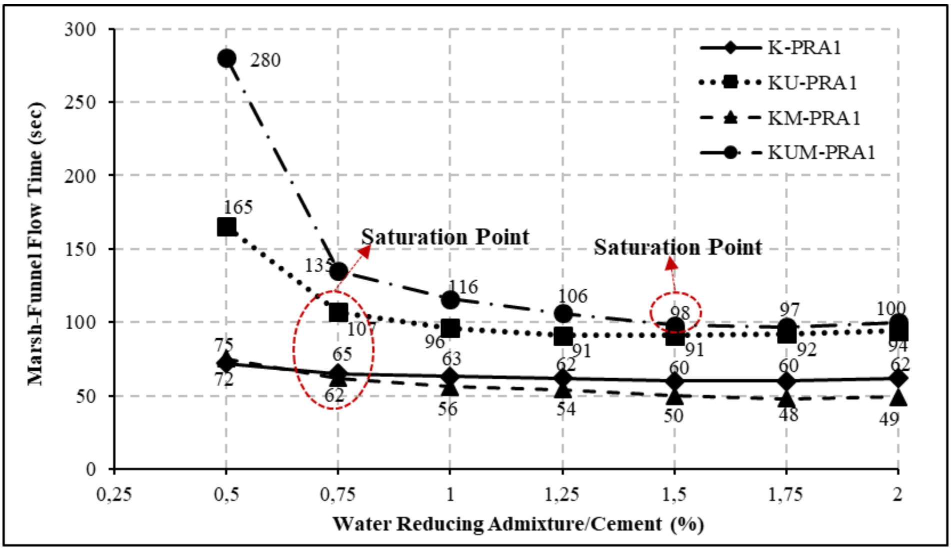

Figure 2. Marsh-funnel flow time of cement pastes containing both mineral admixture and PRA1.

Marsh-funnel flow times, mini-slump and temperature values of the paste mixtures containing control, mineral and “PRA2” permeability-reducing admixtures are shown in Table 10 and Figure 3. Addition of “PRA2" admixture into the control and mineral admixture including mixtures affected initial Marsh-funnel flow times positively except for that of "KM-PRA2" mixture. Saturation points of the mixtures including “PRA2” are observed in different amounts. While the water reducing admixture saturation point of the "K-PRA2" mixture was 0.25% less than that of control mixture, the amount was 0.25% and 0.5 higher in "KM-PRA2" and "KUM-PRA2" mixtures, respectively. "K-PRA2" and "KU-PRA2" mixtures showed 29% and 23% higher Marsh-funnel flow performance at saturation points compared to the "K" and "KU" mixtures without "PRA2”, respectively. However, Marsh-funnel flow time was 28% higher than that of

“KUM” mixture at the saturation point of the "KUM-PRA2" mixture. As observed in "KUM-PRA1" mixture, flow times were affected negatively due to the binder-admixture incompatibility in "KUM-PRA2" mixture including "PRA2" admixture. Thus, it is considered that there is an increase in viscosity values of the mixture.

Increase in mini-slump values of the paste mixtures was observed in the mixtures including "PRA2" independently from mineral admixture type and with the increase of water reducing admixture use. Nevertheless, mini slump values of the "K-PRA2", "KU-PRA2", "KM-PRA2" and "KUM-PRA2" mixtures were affected negatively compared to the mixtures without permeability reducing admixture as in "PRA1" added mixtures. That effect is thought to be as a result of the fact that "PRA2" admixture increased yield stress of the paste mixtures.

Table 10. Marsh-funnel flow time. Mini-slump and the temperature value of cement paste mixtures containing both mineral admixture and PRA2.

Admixture/cement rate (by weight %)		**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2**
Flow time sec	**K-PRA2**	66	61	61	62	60	63	66
	KU-PRA2	112	84	69	67	68	70	71
	KM-PRA2	-	152	73	58	54	54	62
	KUM-PRA2	-	150	91	82	73	73	83
Temperature. °C	**K-PRA2**	35.2	33.5	32.1	32.1	32.1	31.2	30.8
	KU-PRA2	30.3	30.5	32.5	33	32.8	32.1	32.3
	KM-PRA2	-	35	37	38	37.8	34	32.3
	KUM-PRA2	-	35	35.1	32.8	37.2	32.5	32
Mini slump. mm	**K-PRA2**	125	145	150	152.5	152.5	152.5	152.5
	KU-PRA2	120	140	152.5	157.5	160	160	160
	KM-PRA2	-	90	112.5	132.5	142.5	157.5	147.5
	KUM-PRA2	-	112.5	122.5	137.5	147.5	157.5	157.5

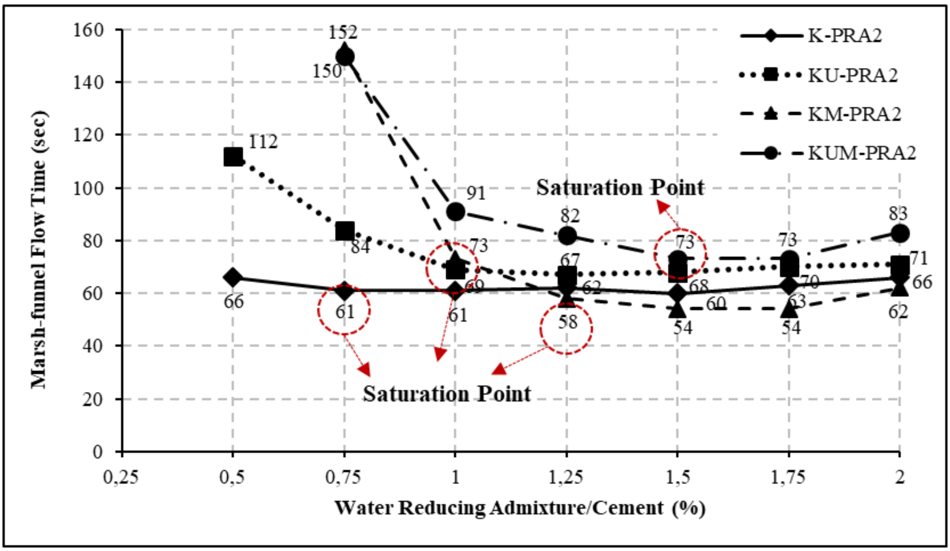

Figure 3. Marsh-funnel flow time of cement pastes containing both mineral admixture and PRA2.

Marsh-funnel flow times, mini-slump and temperature values of the mixtures including control, mineral and "PRA3" permeability reducing admixture are shown in Table 11 and Figure 4. Addition of “PRA3” admixture to the paste mixture affected initial Marsh-funnel flow times of the mineral added mixtures negatively except for the control mixture. Marsh-funnel flow of all other mixtures was affected positively with the addition of “PRA3” admixture into the mixtures with 0.75% water reducing admixture except for the "KM-PRA3" mixture. However, no positive effect was observed in terms of reducing plasticizer saturation point of the mixtures compared to those without permeability reducing admixture. While "K-PRA3" mixture can reach a saturation point with the addition of 1% water reducing admixture, other "KU-PRA3", "KM-PRA3", "KUM-PRA3" mixtures can reach the admixture saturation point with the addition of 1.25% water reducing admixture. KU-PRA3", "KM-PRA3" and "KUM-PRA3" mixtures were able to reach the saturation point with the addition of 0.25% more plasticizer admixture compared to those of without permeability reducing admixture. Marsh-funnel flow times of all mixtures with “PRA3” at saturation point were 41-54% less than those without permeability reducing admixture. Moreover, with the addition of 1% or more water reducing admixture into those mixtures, Marsh-funnel flow performance showed better flow performance than those without permeability reducing admixture. As it can be seen in Figure 4, "KUM-PRA3" mixture showed better flow performance in terms of cement-admixture compatibility.

Apart from mineral admixture type, mini-slump values of the paste mixtures increased along with the increase of water reducing admixture used in the mixtures with "PRA3". However, there was either stabilization or reduction in mini-slump values of the paste mixtures when plasticizer admixture was used in some mixtures. It shows that the mixture is inclined to segregation regarding the fact that the mixtures are flowable. Mini-slump values of the "K-PRA3", "KU-PRA3" and "KM-PRA3" mixtures affected negatively compared to those without permeability reducing admixture as observed in mixtures containing PRA. That effect was as 5%, 20% and 8% for the "K-PRA3", "KU-PRA3" and “KM-PRA3" mixtures, respectively.

Table 11. Marsh-funnel flow time. Mini-slump and the temperature value of cement paste mixtures containing mineral admixture and PRA3.

Admixture/cement rate (by weight %)		**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2**
Flow time. sec	**K-PRA3**	66	54	41	40	40	42	44
	KU-PRA3	-	97	47	39	39	41	45
	KM-PRA3	-	141	48	36	32	32	32
	KUM-PRA3	-	62	40	33	33	32	34
Temperature. °C	**K-PRA3**	29.1	27.4	27.8	27.2	26.9	27.2	27.1
	KU-PRA3	-	38	38	35.8	32.9	32.2	31.8
	KM-PRA3	-	34.3	33.1	31.7	32.5	31.3	31
	KUM-PRA3	-	33.3	34.4	32.6	32.6	32	32.1
Mini slump. mm	**K-PRA3**	157.5	182.5	190	200	202.5	220	200
	KU-PRA3	-	102.5	160	175	192.5	177.5	177.5
	KM-PRA3	-	85	140	172.5	172.5	197.5	185
	KUM-PRA3	-	132.5	172.5	177.5	177.5	182.5	185

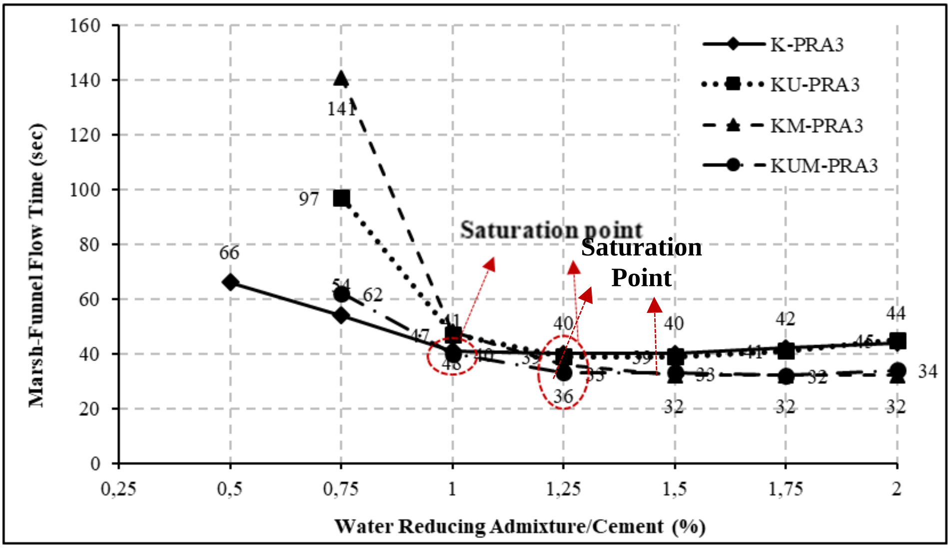

Figure 4. Marsh-funnel flow time of cement pastes containing mineral admixture and PRA3.

3.2. Hardened State Properties

Compressive Strength

The 1, 3, 7, 28 and 90-day values of the prepared mortar mixtures are shown in Table 12 and Figure 5. Compressive strengths of all mixtures increased by elapsed time. Showing nearly 70% less strength performance comparing with the control mixture in terms of the 1-day compressive strength, "K-PRA1" mixture was the least successful mixture. Control, "KU" and "KM" specimens provided close values to each other for 1-day. “KM” mixture was the most successful mixture in terms of strength performance among the mixtures for 3 days and more. This mixture showed 50% more strength especially in 28 and 90 days compared to that of the control mixture. Early age compressive strengths of the mixtures including permeability reducing admixture, except for 7-day "K-PRA2" mixture, were affected negatively compared to the control mixture.

Strength loss at early ages is thought to be as a result of the void entrainment of the permeability admixture to the mixture. According to the manufacturer, the water reducing admixtures used in this study show the air-entrainment property. Considering 90-day mixtures, "PRA2" and "PRA3" admixtures contributed to the strength. Mixtures including mineral admixture “KU” showed less compressive strength performance than the control mixture until 90 days; however, the 90-day compressive strength was less than the control mixture. Including mineral admixture "KM" and "KUM" mixtures, on the other hand, showed higher compressive strengths than the control mixture from 7 days on. This situation is originated from the pozzolanic reaction. Since metakaolin strength activity index is high (110%) and finer in comparison with the cement, compressive strengths of the mixtures with metakaolin became higher than the control mixture in general.

Table 12. The Compressive strength of mortar mixture**.**

	Compressive Strength (MPa)				
Mixture	**1-day**	**3-day**	**7-day**	**28-day**	**90-day**
K	11.43	26.14	37.71	43.49	47.92
KU	10.31	17.37	27.97	40.88	51.64
KM	11.56	29.96	46.64	68.45	72.55
KUM	7.02	22.38	39.51	51.13	52.84
PRA1	3.68	21.84	26.79	35.22	41.01
PRA2	6.54	30.35	36.5	40.54	50.29
PRA3	8.12	22.47	27.14	43.44	49.77

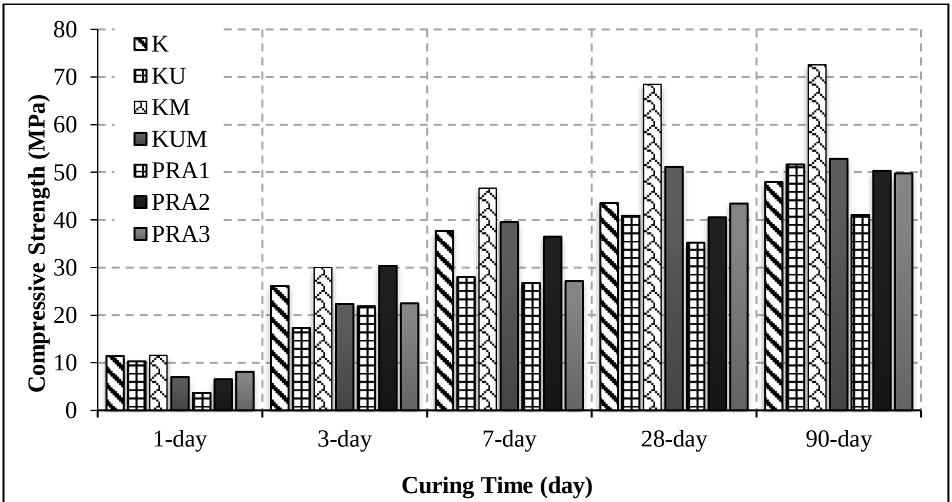

Figure 5. The 1, 3, 7, 28 and 90-day compressive strength of mortar mixture.

4. CONCLUSION

Following results are concluded from the used materials and methods in this study:

1. All mineral added mixtures including 0.5% water reducing admixture by cement weight showed low performance in terms of Marsh funnel flow performance compared to the control mixture. Within this regard, flow performance of the mixtures was affected positively contrary to the expectation, even though the total fine material amount increased with metakaolin use when enough amount of water reducing admixture exists as well as the low performance is observed in terms of flow performance in the mixtures including 40 times finer metakaolin than the cement. This effect is thought to be due to the fact that water reducing admixture can more easily be absorbed in finer grains. Similar results were also emphasized by the other authors.
2. Independent from mineral admixture use and type, Marsh-funnel admixture saturation point of all mixtures is determined when the cement/admixture ratio is 1%. Test results show that the mixtures with a binary cementitious system including metakaolin and fly ash demonstrate the most superior and the worst performances in terms of flow performance compared to the control mixture considering Marsh-funnel flow times at saturation point.

3. Mini-slump values of the paste mixtures increased with the increase of water reducing admixture in the mixtures including mineral admixture. Mini-slump values were stabilized or decreased over a certain admixture ratio.
4. Initial Marsh-funnel flow performances of the mixtures were not significantly affected compared to the mixtures without permeability reducing admixture with the use of PRA1 admixture providing permeability by air-entrainment in the mixture. However, in this mixture, the admixture saturation was realized in lower admixture/cement ratio comparing control mixture. Mineral added mixtures, on the other hand, saturation points of the mixtures were provided with 0.25% less water reducing admixture with the use of permeability reducing admixture called PRA1.
5. It is thought that the PRA1 entrained the air bubbles into the mixture and reduced viscosity and created this positive effect. Mini-slump performances of the mixtures were affected negatively with the addition of PRA1 both into paste mixtures including and excluding the mineral admixture. It is considered that this negative effect is resulted from the PRA1 admixture increasing the yield stress of the mixtures.
6. According to the manufacturer, in the paste mixtures, initial Marsh-funnel flow performances of the mixtures affected positively in general with the addition of PRA2 admixture providing impermeability by filling the pores and capillary pores with hydrophobic chemicals in its structure. Water reducing admixture saturation point for the control mixture without mineral admixture and with the use of mentioned admixture was provided at a lower admixture/cement ratio. However, in the mixtures with mineral admixture, water reducing admixture, caused the reach to the saturation point at higher admixture/cement ratio.
7. Depending upon the manufacturer’s allegation, initial Marsh-funnel flow times were affected negatively with the addition of PRA3 admixture into paste mixtures owing to both the fact that it included insoluble residue and enabled air-entrainment effect. With the addition of the mentioned admixture water reducing admixture saturation point was not considerably affected. However, Marsh-funnel flow time values of the PRA3 added mixtures at the saturation point were less than those without permeability reducing admixture.
8. The 1-day compressive strength value of the mixture including PRA1 admixture was 70% less than that of without mineral and permeability reducing admixture. This mixture was considered as the less successful one in terms of strength at all ages. After 1-day period, the mixture including 10% metakaolin instead of cement by weight with binary cementitious system showed the most successful strength performance. It is considered to be resulting from the pozzolanic reaction because of the higher fineness of the metakaolin. All mixtures including mineral admixture in 90-day specimens showed better performance than control mixture. Other mixtures including permeability reducing admixture except for the PRA2 showed less performance in terms of compressive strength compared to the control mixture.

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