STUDIUL UNOR CARACTERISTICI DE DURABILITATE ALE MORTARELOR PREPARATE CU CIMENT ALB ȘI CIMENT PORTLAND
A STUDY OF SOME DURABILITY PROPERTIES OF MORTARS WITH WHITE CEMENT AND PORTLAND CEMENT

ALI UĞUR ÖZTÜRK[1], GÖKHAN KAPLAN[2*]
[a]Celal Bayar University, Faculty of Engineering, Department of Civil Engineering, Manisa, TURKEY
[b*]Kastamonu University, Kastamonu Vocational Schools Kastamonu, TURKEY

Workability, strength and durability are among the most important properties when working with concrete. Increased compressive strength of concrete has favorable impact on durability along with on its several other features. To ensure a high degree of durability, it is essential that clean, sound materials and the lowest possible water content are used in the concrete, together with thorough mixing. Good consolidation during placement of the concrete is important, as are proper curing and protection of the concrete during the early hardening period, which assure favorable conditions of temperature and moisture. Cure concrete properly for a minimum of three days in order to develop good durability.

In this study mortars with white cement and Portland cement and different w/c ratios were produced and investigated. The mortars produced were then tested for the impacts of alkali silica reaction (ASR), high temperatures, abrasion and acid effect. Results show that less expansion was measured on the mortars using portland cement while the white cement gave the largest expansions (approximate 0.60%).However, there was no significant difference between cements in terms of their acid resistance. The impact of higher temperatures on mortars produced using white cement was less in comparison with normal Portland cement. Durability tests showed that w/c ratio plays an important role.

***Keywords**: White cement, alkali silica reaction, acid effect, high temperature, water/cement ratio*

1. Introduction

Concrete is the most widely manufactured material in the world, with more than one cubic meter produced annually for every person on earth [1]. A typical concrete contains roughly 70 vol.% aggregate embedded in a cementing phase of hydrated ordinary Portland cement (OPC), which, in turn, is primarily composed of tri- and dicalcium silicate phases (known as alite and belite, respectively) [2]. When exposed to water, calcium silicates form calcium hydroxide and calcium silicate hydrate (C-S-H) gel, a cohesive phase that is the source of compressive strength in conrete [3-5].White cement is also a Portland cement and the process of its manufacturing is quite similar to normal (ASTM Type I or II) grey cement and, except for colour, it has essentially the same properties as grey cement. A controlled manufacturing process for white cement includes selective raw materials with low amounts of colouring elements. Fe, Co, Mn, Cr, Ni are well known chromophores responsible for a mineral's colour [6].

A heterogeneous chemical reaction between ions and alkalis dissolved in the concrete pore solution and certain types of siliceous aggregates known as alkali–silica reaction (ASR) makes one of the most deleterious mechanisms of the damage of concrete structures throughout the world [7,8]. Eventually recognition of the progressive destruction in situ [9,10], the mitigation of ASR is focused on preventive recognition of reactive or potentially reactive forms of aggregates by laboratory studies [11,12]. These involve various petrographic techniques focused on the detection of reactive forms of silica in aggregate source rocks [13] and on accelerated laboratory test aiming to initiate ASR within tested concrete mixture in a short period of time [14,15]. The accelerated mortar bar test ASTM C1260 [16] is the most common laboratory test method which contributes to the recognition of the ASR potential of aggregates based on the expansion values of experimental concrete mixtures. This method is considered as a reference test worldwide due to its simplicity [17].

It is well established that mechanical properties of concrete are adversely affected by thermal exposure. Concrete typically loses between 10 to 20% of its original compressive strength when heated to 300 °C, and between 60 to 75% at 600 °C [18]. Typically, a hydrocarbon fire can generate temperatures in excess of 1000 °C with heat fluxes around 150 kW/m^2 within minutes of ignition [19,20]. Additionally, a hydrocarbon jet fuel can have the same temperatures, but the heat flux

* Autor corespondent/*Corresponding author*,
E-mail: gkaplan@kastamonu.edu.tr

could be doubled [19,20]. At these temperatures, the compressive strength of Portland cement concrete can be reduced by as much as 90% [19]. This loss of strength is commonly attributed to the degradation of the calcium silicate hydrate (C-S-H) as it begins to lose structural water along with dehydration (evaporation of capillary water) of other hydrates (e.g., calcium hydroxide ($Ca(OH)_2$) and ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$)) and initiation of internal thermal stress gradients. In addition, high-density, high-performance concretes (HPCs) with high amounts of Portland cement and low water-to-cementitious materials ratios have problem when are exposed to high temperatures. HPCs have a high density with low porosity, and as temperature increases the water vapor is unable to escape, causing pressure to build-up in the pores that results in explosive spalling [21-23].

Another important property of concrete is abrasion resistance which is surface resistance to rub of substances from top of concrete surface. The abrasion resistance of concrete is defined as the “ability of a surface to resist being worn away by rubbing and friction”. Abrasion of floors and pavements can result from production operations, or foot or vehicular traffic; therefore, abrasion resistance is of concern in industrial floors [24]. Abrasion resistance of concretes is directly related to concrete strength, cement dosage, water-cement ratio, surface finishing etc. Previous studies demonstrated that higher the compressive strength of concretes lower the rubbed of substances from the concrete surface [25]. Concrete in hydraulic structures, especially in spillway, flood discharge tunnel, overflow surface, sea-crossing bridge piers etc., will deteriorate severely by water flow containing solid particles, such as sand and water-borne debris. In general, the velocity of water flow in hydraulic structures does not exceed 40 m/s. However, in some extreme cases, the hydraulic structures deteriorate seriously due to the concrete at the surface removes quickly with high velocity water flow (>40 m/s) containing solid particles. Hydraulic structures usually suffer of cause of high velocity water flow containing solid particles in the spillway, the flood discharge tunnel, or on the overflow surface, and thus, the designing of abrasion erosion resistant materials is still a big challenge [26].

Concrete structures are regularly subjected to aggressive environmental conditions from a variety of naturally-occurring and industrial chemicals. Sulphuric acid (H_2SO_4) is one of the most destructive to concrete structures due to its presence in ground water, industrial waste and sewage systems [27]. Interaction between concretes and sulfuric acid causes substantial and rapid degradation and damage. Although sulfuric acid is always hazardous to cementitious material [28], cement type and content are important factors affecting performance in sulfuric acid environments [29]. According to Turkel et al. [30], the alkalinity of hardened cement binders, which is responsible for binding properties, may be partially or completely neutralized when sulfuric acid reacts with hydration products such as calcium hydroxide (CH) or calcium silicate hydrates (C-S-H).

This research aimed to characterise durability- related properties and compressive strength of cement mortar prepared with a commercial cement (ordinary Portland cement and white cement) at different w/c ratios, for use in ready mix and architectural concrete. In this context, properties such as alkali silica reaction (ASR), high temperatures resistance, abrasion and durability against acidic substances were examined.

2. Materials and methods

2.1. Materials

White cement and normal Portland cement were used as binders in this study. Physical and chemical characteristics of the used cements are shown in Table 1.

Table 1
Chemical and physical characteristics of the cements

Chemical Composition	White Cement	Normal Portland Cement
CaO	65,9	62,51
SiO_2	21,1	20,33
Al_2O_3	4,10	5,55
Fe_2O_3	0,20	3,10
SO_3	3,33	3,23
MgO	1,27	1,76
Na_2O	0,31	0,35
K_2O	0,34	0,89
Free CaO	1,63	0,96
Cl	0,01	0,01
Loss on Ignition	3,15	1,19
Insolubles	0,15	0,30
Specific Weight	3,05	3,15
Blaine	4700	3250
Initial setting time	110	120
Final Setting	145	180

Two types of aggregates were used for mortars preparation. The samples prepared for testing against the impact of acids, high temperature and abrasion consist of standardised sand (silica sand) which complies with TS EN 196-1 standard. The samples prepared for ASR tests, on the other hand, contained natural aggregate obtained from the Ahmetli district of the city of Manisa. Physical properties of the Ahmetli aggregate are shown in Table 2.

Amounts of materials used in the preparation of the mortar mixtures are given in Table 3 (in grams).

Table 2

Physical properties of the aggregate

Sieve Analysis		Specific Weight
Sieve Size	% Passing Through the Sieve	2,66
3/8"	100	Water Absorption
No:4	95,1	1,65
No:8	74,4	Fineness Modulus
No:16	60,2	3,0
No:30	48,8	
No:50	22,7	
No:100	4,5	

Table 3

Compositions of the cement mortars

Durability test	Mixtures compositions			
	Aggregate (g)	Water (g)	Cement (g)	W/C
ASR	1350	282	600	0,47
	1350	420	600	0,70
Impact of High Temp.	1350	315	450	0,70
Impact of Abrasion Impact of Acid	1350	225	450	0,50

2.2. Method

Accelerated Mortar-Bar Method (25x25x285 mm) was used in order to investigate the ASR effect in compliance with the ASTM C 1260 standard. Creek sand of high alkali content obtained from the Ahmetli district of the city of Manisa was used as the aggregate. Nevertheless, normal (grey) Portland and white Portland cements were used as binder and mortar bars with 0.47 and 0.70 W/C ratios were prepared. For the tests, the mixtures were cast in 40mm×40mm×160mm and 25mmx25mmx285 mm molds and demolded at 24 h after casting. Then the mortar prisms were placed in water with temperature of 20 and 80°C until the testing. After 1st, 3rd, 7th and 14th days of water curing, the mortar bars were placed in NaOH solution at 80 ^{0}C.

Cube samples of 5cmx5cmx5cm were used in order to study the impact of high temperatures. Removed from the molds after 24 hours, mortar samples were then exposed to water curing for 28 days. After that, mortar samples were thermic treated in the oven at 300°C and 600°C for 3 hours. Then, half of the samples were cooled at room temperature while the other half were cooled in water.

Cubic samples of 7.1cmx7.1cmx7.1 cm were prepared in order to investigate the abrasion resistance. The mortar samples were cured in water for 7 and 28 days. After this curing, their abrasion resistance was determined using a Böhme device. Edges and weights of the cubic samples were measured before the tests. One face of the cubic samples was exposed to abrasion from four directions using corundum dust. Edges and weights of the initial, cubic samples were then measured again at the end of the tests.

Sulfuric acid was used in order to determine the acid resistance. The mortar samples of 5cmx5cmx5 cm were cured in water for 28 days. After that, the mortar samples were kept in sulfuric acid solution of four different concentrations: 0.5%, 1.0%, 3%, and 7%, for 21 days. After this curing period of time, the mortar samples were investigated for their compressive strength.

3. Results and discussion

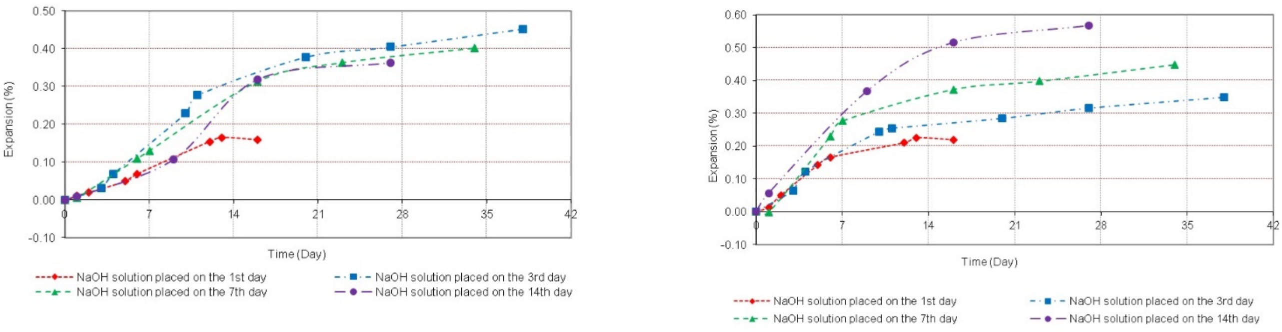
3.1. Alkali Silica Reaction

Figure 1 shows the ASR expansion of the mortars samples obtained using Portland cement. Figure 1a shows the ASR expansion of mortar samples with a w/c ratio of 0.47. The highest ASR expansion was observed for the mortars placed in NaOH solution at the end of 3 days.

Figure 1b shows a significant increase in the ASR expansion when the w/c ratio is 0.70. It was found that the mortars placed in the NaOH solution at the end of the 14th day were adversely affected by the ASR. It was shown that all the samples went beyond 0.20 % expansion at the end of the 14th day. ASR expansion is approximately with 38% greater when the w/c ratio is 0.70.

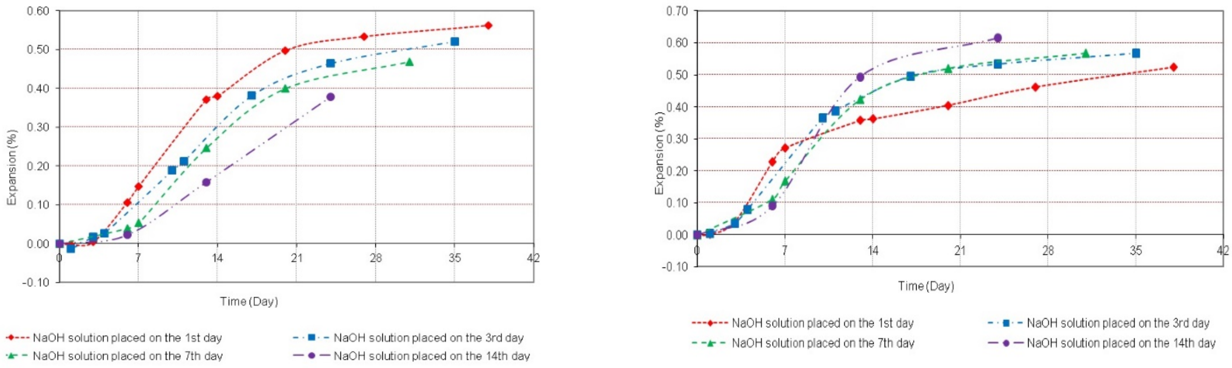
Figure 2 shows the ASR expansion of the mortars samples obtained using white cement. Particularly, the mortar samples which were placed in the NaOH solution at the end of the 1st day reached at the maximum expansion.

However, this effect differs when the w/c ratio is 0.70. Figure 2b shows that all mortar samples had greater of 0.10 % (Limit value for ASTM C 1260) expansion at the end of the 14th day when w/c ratio is 0.70. ASR expansion increases with aproximately 57% when w/c ratio is 0.70. Moreover, it was found that white cement is more susceptible to ASR expansion when compared to Portland cement.



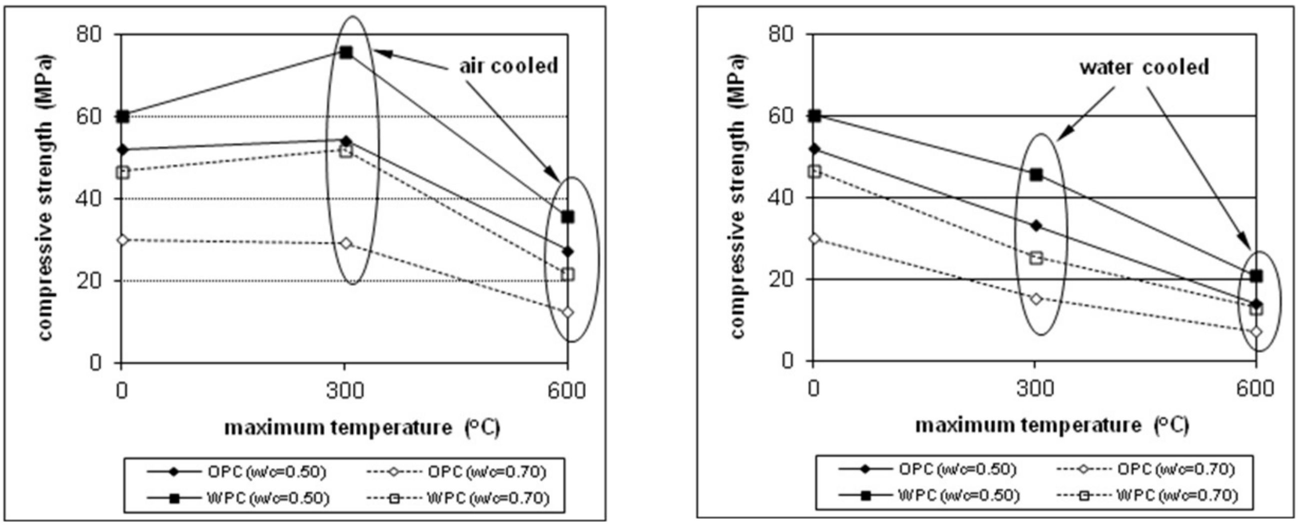
a b

Fig. 1- ASR expansion of the mortar samples with Portland cement: a - prepared with w/c ratio of 0.47; b – prepared with w/c ratio of 0.7



a b

Fig. 2 - ASR expansion of the mortar samples with White cement: a - prepared with w/c ratio of 0.47; b – prepared with w/c ratio of 0.7



a b

Fig. 3 - The impact of air cooling and water cooling on the mortars samples exposed to high temperatures.

3.2. Impact of high temperature

Figure 3 shows the compressive strength of the mortars exposed to high temperatures. Figure 3a show that air cooling has an impact on the compressive strength, in correlation with temperature treatment. For the samples heated at 300°C air cooling does not have unfavorable impact on strength. However, compressive strength decreases with 35-43% when the samples were heated at 600°C.

Figure 3b shows the changes in the compressive strength of the mortars samples exposed to high temperatures when they were cooled in water. This had an adverse impact on the compressive strengths of samples heated at both 300°C and 600°C. Water cooling of the samples heated at 300°C led to a decrease in compressive strengths between 16% and 40%. For the samples heated to 600°C the decrease in compressive strengths was between 65% and 67%. The w/c ratio and the cooling method have an important impact on the mortars exposed to higher temperatures.

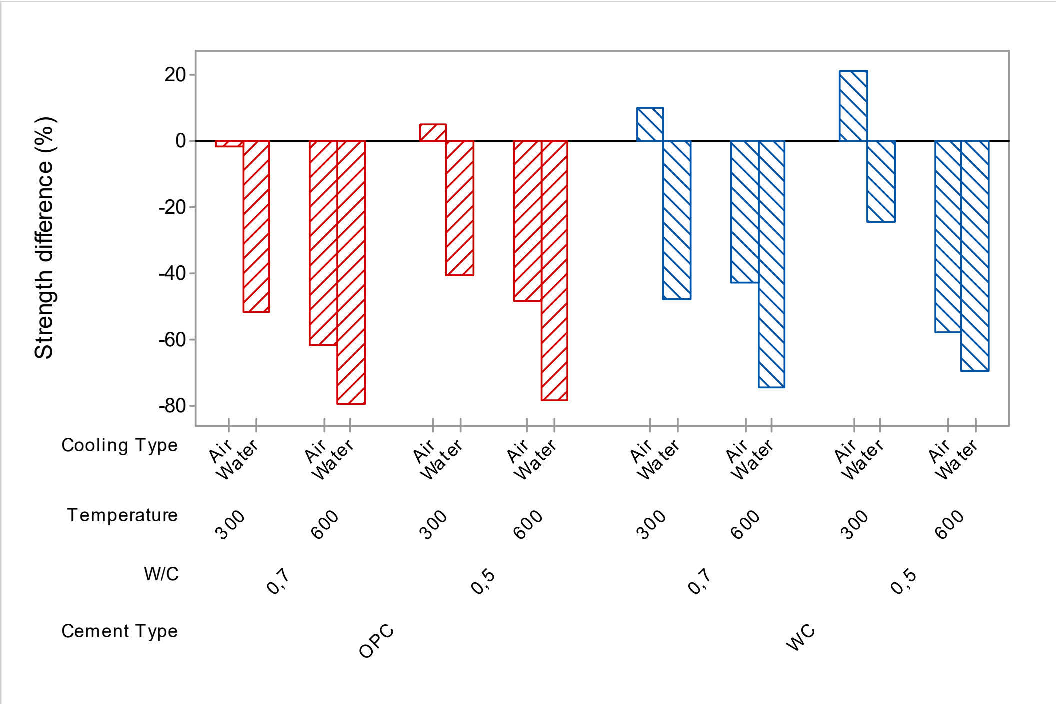
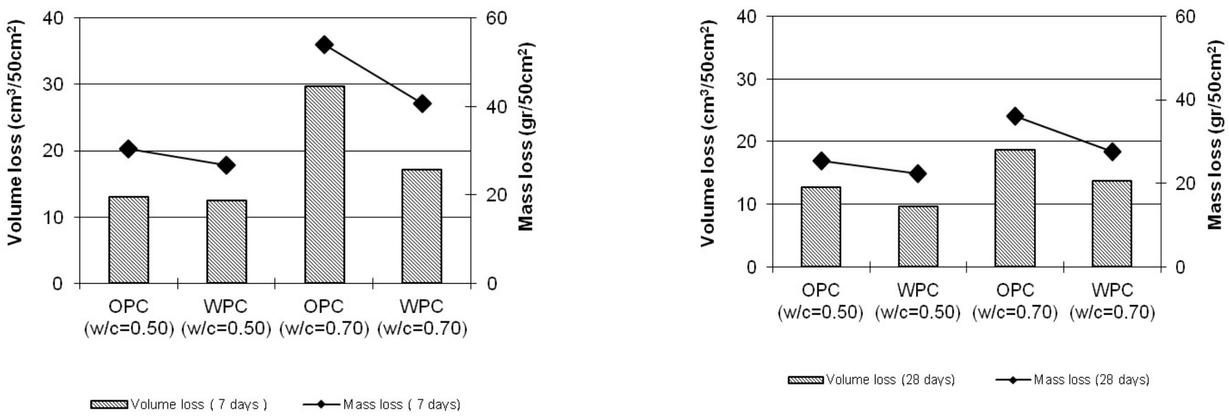


Fig. 4 - The impact of high temperature on the loss of strength



a b

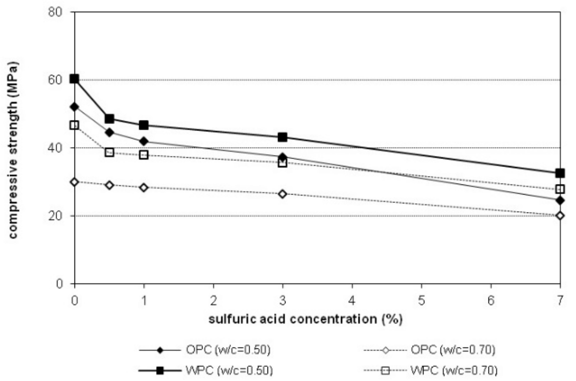
Fig.5 - The Impact of curing time, w/c ratio and cement type on abrasion.

As is shown in Figure 4, air cooling of the sample heated at 300°C has favorably results in terms of compressive strength. Especially the mortars obtained using white cement show improved strength. Increased w/c ratio adversely affects the compressive strength. Nevertheless, the loss of strength is at a higher level for the mortars obtained using normal Portland cement.

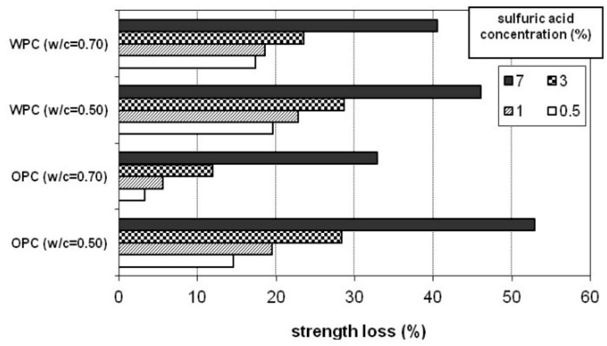
3.3. Impact of Abrasion

Figure 5 shows the weight and volume losses as result of abrasion for the mortars samples prepared using white cement and Portland cement. Figure 5a shows the weight and volume losses according to the abrasion conducted at the end of the 7th day of water curing. A significant difference was detected between the two cements samples when the w/c ratio is 0.50. However, it was found that normal Portland cement is adversely affected by abrasion when the w/c ratio is 0.70. The weight loss of normal Portland cement due to abrasion increased with 125% when the w/c ratio is 0.70. For the same w/c ratio, the weight loss of white cement due to abrasion increased with 32%.

Figure 5b shows the impact of abrasion on the weight and volume losses when the water curing time was 28 days. It was found that the weight and volume losses of the mortar samples from white cement were lesser than the weight and volume losses for normal Portland cement mortar. Weight loss of the mortar obtained using normal Portland cement increased with 47% when the w/c ratio was 0.70. However, the weight loss of the white cement mortar was at 18% (w/c=0,70). It was found that curing time and w/c ratio play an important role in the impact of abrasion.



a



b

Fig.6 - Compressive strength of the mortars exposed to sulfuric acid.

3.4. Impact of acid attack

Mortars obtained using white cement and normal Portland cement were exposed to sulfuric acid of different concentrations. Figure 6 shows the changes in the compressive strengths of the mortars.

Mortar samples lose their strength as the sulfuric acid concentration increases (Fig. 6a). Compressive strength of mortars with w/c ratio of 0.5 prepared using white cement decreased with 46% when the sulfuric acid concentration was 7%. The review of all sulfuric acid concentrations revealed that the normal Portland cement mortar with w/c ratio of 0.50 showed the highest loss in strength (Fig. 6b). However, this effect is reverse when the w/c ratio is 0.70. Strength loss of the mortar obtained with normal white cement increases as the w/c ratio increases. However, this was not the case for the mortars obtained using Portland cement.

4. Conclusions

Mortars obtained using white cement proved a higher level of expansion when they were investigated in terms of ASR. Increase of W/C ratio generally leads to the increase of ASR expansion. This could be explained by the increase of capillary porosity of the mortar.

Air cooling of the sample heated at 300°C has a favorably influence on compressive strength. However, air cooling of the samples heated at 600°C has an unfavorable impact on the compressive strength. Water cooling, on the other hand, has a significantly unfavorable impact on the compressive strengths of the samples thermic treated. The impact of higher temperatures on mortars prepared with white cement was lesser in comparison with their impact on normal Portland cement.

Weight loss by abrasion of the mortars samples prepared with white cement was lower in comparison with that of samples with Portland cement. It was found that w/c ratio is the most significant parameter for the abrasion resistance.

There was no significant difference between white cement and normal Portland cement in terms of their acid resistance. Nevertheless, it was shown that the w/c ratio has a more important impact.

Durability tests showed that w/c ratio plays an important role for this property. However, the strength class of the cement gains importance over the cement type when physical effects such as abrasion are in question.

REFERENCES

1. E. Gartner, Industrially interesting approaches to ''low-CO_2'', cements. Cem Concr Res 2004, **34**(9), 1489.
2. HM Jennings, JW Bullard, From electrons to infrastructure: engineering concrete from the bottom up, Cem Concr Res 2011, **41**(7), 727.
3. Bullard JW et al. Mechanisms of cement hydration, Cem Concr Res 2011;41(12):1208–23.
4. A. Neville, The confused world of sulfate attack on concrete, Cem Concr Res 2004, **34**(8), 1275.
5. C. Horsley, MH Emmert, A. Sakulich, Influence of alternative fuels on trace element content of ordinary Portland cement, Fuel 2016, **184**, 481.
6. N. Ertek, F. Öner, Mineralogy, geochemistry of altered tuff from Cappadocia (Central Anatolia) and its use as potential raw material for the manufacturing of white cement, Applied Clay Science, 2008, **42**, 300.
7. R. Narayan Swamy (Ed.), The Alkali–Silica Reaction in Concrete, CRC Press, 2002.
8. B. Fournier, M.A. Bérubé, Alkali-aggregate reaction in concrete: a review of basic concepts and engineering implications, Can. J. Civ. Eng. 200, **27** (2), 167.
9. P. Rivard, F. Saint-Pierre, Assessing alkali–silica reaction damage to concrete with non-destructive methods: from the lab to the field, Constr. Build. Mater. 2009, **23**, 902.
10. P. Rivard, G. Ballivy, Clermont Gravel, Francois Saint-Pierre, Monitoring of an hydraulic structure affected by ASR: a case study, Cem. Concr. Res., 2010, **40**, 676.
11. J. Lindgård, Ö. Andiç-Çak, I. Fernandes, T.F. Rønning, M.D.A. Thomas, Alkali silica reactions (ASR): literature review on parameters influencing laboratory performance testing, Cem. Concr. Res. 2012, **42**, 223.
12. L.J. Malvar, G.D. Cline, D.F. Burke, R. Rollings, T.W. Sherman, J.L. Greene, Alkali–silica reaction mitigation: state of the art and recommendations, ACI Mater. J. 2002, **99** (5).
13. I. Sims, P. Nixon, RILEM recommended test method AAR-1: detection of potential alkali-reactivity of aggregates—petrographic method, Mater. Struct. 2003, **36** (7), 480.

14. M. Thomas, B. Fournier, K. Folliard, J. Ideker, M. Shehata, Test methods for evaluating preventive measures for controlling expansion due to alkali–silica reaction in concrete, Cem. Concr. Res. 2006, **36**(10), 1842.
15. S. Chatterji, Chemistry of alkali–silica reaction and testing of aggregates, Cem. Concr. Compos. 2005;27(7):788–795.
16. ASTM C1260-07 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-bar Method), vol. 04.02, ASTM C1260, West Conshohocken, 2011.
17. Lokajíc T, Kuchar A, Petruz M, Šachlová Š, Svitek T, Pr˘ikryl R. Semi-continuous ultrasonic sounding and changes of ultrasonic signal characteristics as a sensitive tool for the evaluation of ongoing microstructural changes of experimental mortar bars tested for their ASR potential, Ultrasonics, 2016, **71**, 40.
18 L.T. Phan, N.J. Carino, Fire Performance of High Strength Concrete: Research Needs, NIST, 2000.
19. European Association for Passive Fire Protection, Hydrocarbon, 1987, www.eapfp.com/hydrocarbon.php.
20. ASTM E1529-14a, Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies 1, 2016 1–25, http://dx.doi.org/10.1520/E1529-14A.and
21. F.A. Ali, D. O'Connor, A. Abu-Tair, Explosive spalling of high-strength concrete columns in fire, Mag. Concr. Res. 2001, **53**, 197, http://dx.doi.org/10.1680/macr.2001.53.3.197.
22. F. Ali, A. Nadjai, D. Talamona, Assessment of the susceptibility of normal and high strength concrete for explosive spalling, J. Appl. Fire Sci. 2005, 13, 79.
23. O.G. Rivera, W.R. Long, C.A. Weiss Jr, R.D. Moser, B.A. Williams, K. Torres-Cancel,E.R. Gore, P.G. Allison, Effect of elevated temperature on alkali-activated geopolymeric binders compared to portland cement-based binders, Cement and Concrete Research 2016, **90**, 43.
24. ACI Committee 201, Guide to Durable Concrete, ACI Mater. J. 1991, **88**(5), 544 (September–October).
25. M Balcikanli, Hakan Tacettin Turker, E Ozbay, O Karahan, C.D. Atis, Identifying the bond and abrasion behavior of alkali activated concretes by central composite design method, Construction and Building Materials 2017, **132**, 196.
26. XC Zhen He, ST Xiaorun Chen, Abrasion erosion characteristics of concrete made with moderate heat Portland cement, fly ash and silica fume using sandblasting test, Construction and Building Materials, 2016, **127**, 804.
27. ACI Committee Report 201, Guide to Durable Concrete ACI Manual of Concrete Practice, American Concrete Institute, 2001.
28. L.J. Parrot, Carbonation, moisture and empty pores, Adv. Cem. Res. 1992, **4**(15), 111.
29. H. Siad, H.A. Mesbah, H. Khelafi, S. Kamali-Bernard, M. Mouli, Effect of mineral admixture on resistance to sulphuric and hydrochloric acid attacks in self compacting concrete, Can. J. Civ. Eng. 2010, **37**(3), 441.
30. S. Turkel, B. Felekoglu, S. Dulluç, Influence of various acids on the physico mechanical properties of pozzolanic cement mortars, Sadhana, 2007, **32**(6), 683.

****

MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

METZ
F R A N C E

OCT.11th - 13th, 2017

EUROSLAG The European Association representing metallurgical slag producers and processors

Afoco ASSOCIATION FRANCAISE DES OPERATEURS SUR CO-PRODUITS INDUSTRIELS

The 9th EUROPEAN SLAG CONFERENCE will take place in METZ, FRANCE, at the prestigious Arsenal, from October 11th to 13th, 2017, organized by EUROSLAG with the local support of AFOCO, the French Industrial Co-Products Operators Association.

EUROSLAG, created in 2000, is the federation of all main European organizations and companies concerned with all aspects of manufacturing and utilization of ferrous slag products. www.euroslag.org

The Association deals with promotion of slag as a product, enables exchange of information and research and facilitates the interaction with governing bodies. About 45 million tons of ferrous slags are generated annually in Europe by iron and steel plants.

AFOCO, Member of EUROSLAG, is the French Association of companies involved in collecting slags and other by-products in the steel plants with the aim to transform them into useful and reliable new products. AFOCO brings together 18 companies which manage about 90% of all the French slag production, including some of the best research teams in this field.

The purpose of the 9th EUROPEAN SLAG CONFERENCE is the exchange of knowledge related to technical applications, environmental and legal subjects for all kinds of iron and steel slags.

****