Performance of Cement Containing Laterite as Supplementary Cementing Material

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The utilization of different industrial waste, by-products or other materials such as ground granulated blast furnace slag, silica fume, fly ash, limestone, and kiln dust, etc. as supplementary cementing materials has received considerable attention in recent years. A study has been conducted to look into the performance of laterite as Supplementary Cementing Materials (SCM). The study focuses on compressive strength performance of blended cement containing different percentage of laterite. The cement is replaced accordingly with percentage of 2 %, 5 %, 7 % and 10 % by weight. In addition, the effect of use of three chemically different laterites have been studied on physical performance of cement as in setting time, Le-Chatlier expansion, loss on ignition, insoluble residue, free lime and specifically compressive strength of cement cubes tested at the age of 3, 7, and 28 days. The results show that the strength of cement blended with laterite as SCM is enhanced.

Key words: *Portland cement, supplementary cementing materials (SCM), laterite, compressive strength*

Introduction

During the last decades, the use of by-product materials and cement-strengthening materials is increasing. Blended cements are one of the good additions as an environmental sustainable material along with cost effective nature.[1–5] It includes use of pozzolanic material i.e. fly ash, silica fume, blast furnace slag and non-pozzolanic materials i.e limestone etc.[6–8]

Laterite is naturally occurring pozzolanic material. It has been known in Asian countries as a building material for more than 1000 years.[9] It was excavated from the soil and cut in large blocks; temples at Angkor are famous examples of this early use.[10] Laterite deposits were found in the tropical and inter-tropical areas.[11] Large deposits of laterite were found in Ziarat area, Sibi, Loralai[12,13] and Muzaffarabad.[14]

Due to immense applications and utility, "Eurolat" was started in 1984 by French geoscientists as "European Network on Tropical Laterites". Moreover, an "International Interdisciplinary Laterite Reference Collection (CORLAT)" was established at the "International Soil Reference and Information Centre (ISRIC)" at Wageningen, the Netherlands.[15]

This study focuses on the strength performance of cement with different types of laterite based on different oxide composition. Strength is the most important property of cement since the first consideration in structural design, i.e. the structural elements, must be capable of carrying the imposed loads. The strength characteristic is also important because it is related to several other important properties e.g., fineness, permeability, extent of cement hydration etc, which are more difficult to measure directly.

Experimental

The materials used in this study were cement (Table 1) and three laterites of different chemical composition i.e., laterite A (high iron), laterite B (low alumina), laterite C (high alumina) shown in the Table 2. Firstly, the laterite was crushed using mesh size less than 5 mm by jaw crushers, and dried at 110 °C in an electric oven. The dried laterite was converted to the size of cement i.e., less than 200 micrometer by using disc mill. The laterite and cement are blends on the basis of mass fractions shown in Table 3. The samples in a given quantity (Table 4) were taken at the precision level of ±0.01 g and blended in Turbula mixer (Turbula Model T2C Shaker Mixer Blender, 1995 model) for 10 minutes for each sample.

The compositions of different constituents were determined by PANalytical Cubix XRF. Different properties of blended cement were determined according to ASTM i.e., Blaine by air permeability apparatus (C0204-00),[16] normal consistency (C0187-04),[17] setting time (C0191-04B),[18] compressive strength (C0109M-02),[19] free lime and insoluble residue (C0114-05)[20]and Le-Chatelier expansion by (BS EN 196-3).[21]

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Table 1 – *Chemical Analysis of Representative OPC Sample*

Tablica 1 – *Kemijska analiza reprezentativnog uzorka običnog portland-cementa (OPC)*

Compound Spoj	*w* / %
SiO_2	21.19
Al_2O_3	5.61
Fe_2O_3	3.15
CaO	63.80
MgO	1.71
K_2O	0.80
Na_2O	0.23
SO_3	2.34
LSFc	91.42
S.M.	2.42
A.M.	1.78
C_3S^*	62.81
C_2S^*	15.18
C_4AF^*	10.49
C_3A^*	10.17
Free CaO* Slobodan CaO*	0.69

* mineral phases determined at high temperature XRD (PANalytical Cubix^3 XRD)

* mineralne faze određene XRD-om na visokoj temperaturi (PANalytical Cubix^3 XRD)

Table 2 – *Chemical composition of selected laterite*

Tablica 2 – *Kemijski sastav odabranog laterita*

Compound Spoj	Laterite type Tip laterita		
	High iron (A) Bogat željezom (A)	Low alumina (B) Siromašan glinicom (B)	High alumina (C) Bogat glinicom (C)
	w / %		
SiO_2	21.65	45.28	22.21
Al_2O_3	11.54	4.61	27.93
Fe_2O_3	50.05	34.65	30.08
CaO	5.05	3.65	3.31
MgO	1.99	0.97	2.0
K_2O	0.7	0.9	0.11

Results and discussion

Specific surface area (Blaine)

Grinding of all three types of laterite shows different behavior. Ease of grinding is an important parameter to decrease the energy cost. It is seen that, under normal conditions, laterite B is ground finer than laterite A and laterite C as well as OPC. Laterite addition in cement increased its fineness. The compressive strength as well as other physical properties were affected by the fine grinding of cement.

Table 3 – *Scheme of blending weights*

Tablica 3 – *Udjel komponenti za pripravu uzorka*

Serial number Redni broj	Blend name Oznaka smjese	*m*(OPC) / g	*m*(laterite) / g *m*(laterit) / g
1	OPC	5000	0
2	02%A	4900	100
3	05%A	4750	250
4	07%A	4650	350
5	10%A	4500	500
6	02%B	4900	100
7	05%B	4750	250
8	07%B	4650	350
9	10%B	4500	500
10	02%C	4900	100
11	05%C	4750	250
12	07%C	4650	350
13	10%C	4500	500

Table 4 – *Chemical compositions of OPC and laterite blends by PANalytical Cubix WD-XRF*

Tablica 4 – *Kemijski sastavi mješavina OPC-a i laterita prema PANalytical Cubix WD-XRF*

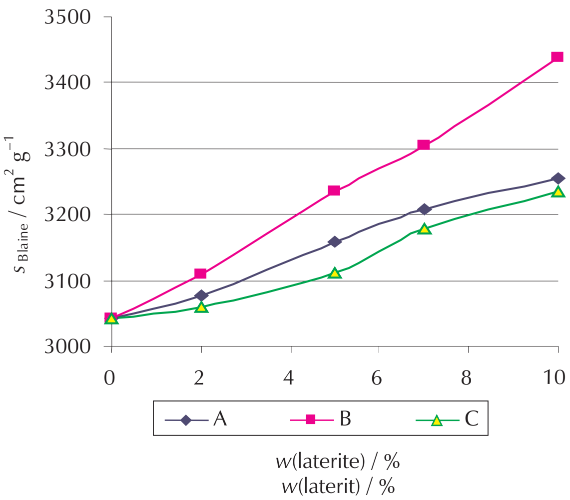
Blend Smjesa	*w* / %								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl
OPC	21.19	5.61	3.15	63.80	1.71	0.80	0.23	2.34	0.0034
02%A	21.18	5.73	3.79	62.46	1.68	0.25	0.77	2.32	0.0034
05%A	21.19	5.88	4.9	61.39	1.69	0.25	0.75	2.25	0.0034
07%A	21.19	5.98	5.64	60.84	1.68	0.24	0.74	2.22	0.0034
10%A	21.23	6.13	8.79	59.9	1.71	0.24	0.73	2.16	0.0034
02%B	21.41	5.57	3.66	60.58	1.58	0.25	0.77	2.31	0.0034
05%B	21.68	2.53	4.45	61.47	1.58	0.24	0.76	2.24	0.0034
07%B	21.88	5.54	4.99	60.63	1.57	0.23	0.74	2.19	0.0034
10%B	22.1	5.53	5.6	59.74	1.5	0.23	0.73	2.1	0.0034
02%C	21.23	6.08	3.57	62.51	1.67	0.24	0.77	2.32	0.0034
05%C	21.23	6.67	4.26	61.42	1.64	0.24	0.76	2.25	0.0034
07%C	21.23	7.04	4.65	61.02	1.65	0.23	0.76	2.2	0.0034
10%C	21.24	7.7	5.32	59.85	1.67	0.23	0.74	2.15	0.0034

Water demand

The Water demand for all types of laterites was decreased to very low i.e., 26.8 to 26.3 % as there is replacement of cement which actually needs water for its hydration and hydrolysis reactions as given in Fig. 2.

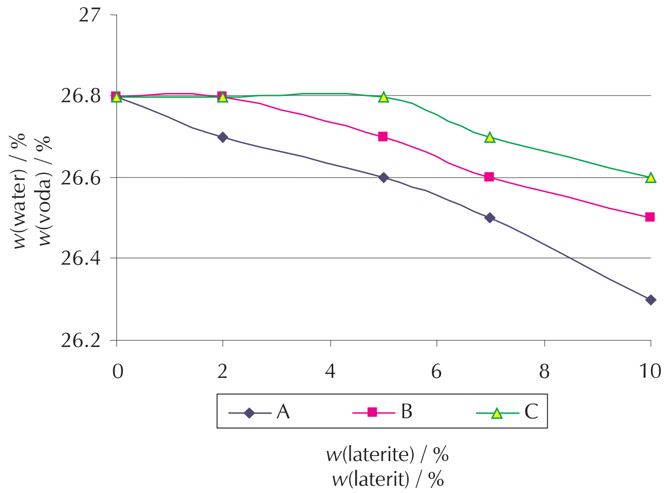
Setting time

Chemical composition, particle size and specific surface area plays an important role in determining the setting



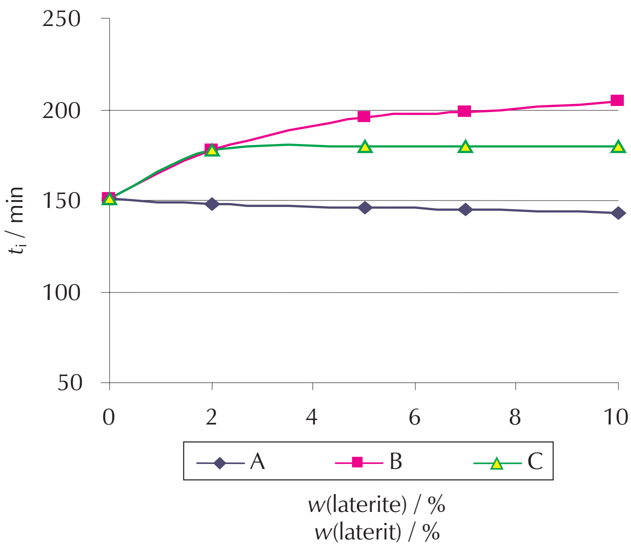
F i g. 1 – *Comparison of specific surface area of OPC and laterite blends*

S l i k a 1 – *Usporedba specifičnih površina smjesa OPC-a i laterita*



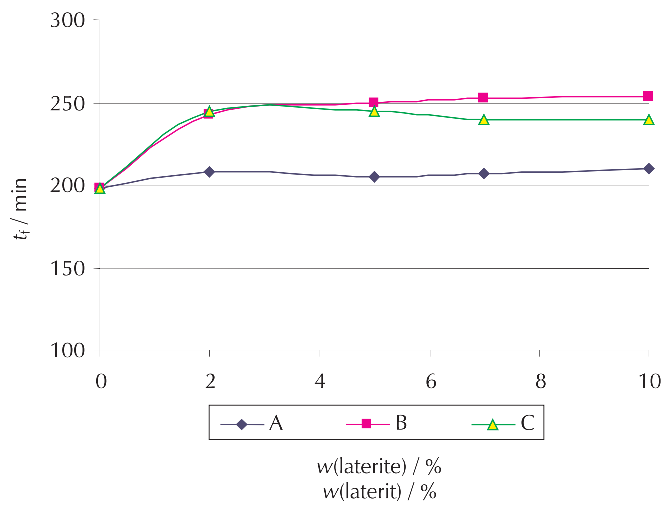
F i g. 2 – *Comparison of water consistency of OPC and laterite blends*

S l i k a 2 – *Udjel vode u smjesi za standardnu konzistenciju smjesa OPC-a i laterita*



F i g. 3 – *Comparison of initial setting times of OPC and laterite blends*

S l i k a 3 – *Usporedba početnih vremena vezanja mješavina OPC-a i laterita*



F i g. 4 – *Comparison of final setting times of OPC and laterite blends*

S l i k a 4 – *Usporedba konačnih vremena vezanja mješavina OPC-a i laterita*

characteristics of cement. Figs. 3 and 4 show that the initial and final setting times for all the blends increased in relation to OPC, this is due to slow pozzolanic reaction, because silica and alumina in laterite consume the early CH formed.[22] As in the case of laterite A and laterite C, the amount of silica and alumina is low, thus there is no major effect of laterite blending, whereas in case of laterite B, the quantity of silica is high due to fine admixture effect, which is responsible for increasing the setting time.

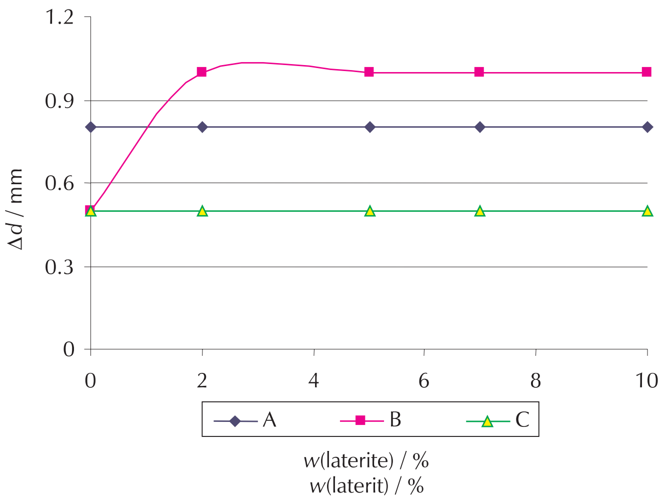
Soundness (Le-Chatelier)

Le Chatelier expansion of Laterite C cement blend is increased to maximum up to 1 mm while expansion for the other two is less than 1 mm, but it should be noted that the expansion is within limits of BS EN 197-1.[23] The increase in value corresponds with the presence of free lime and alkalis (Fig. 5). It can be indicated that the effect of adding laterite increases the soundness of the resultant cement.

Compressive strength

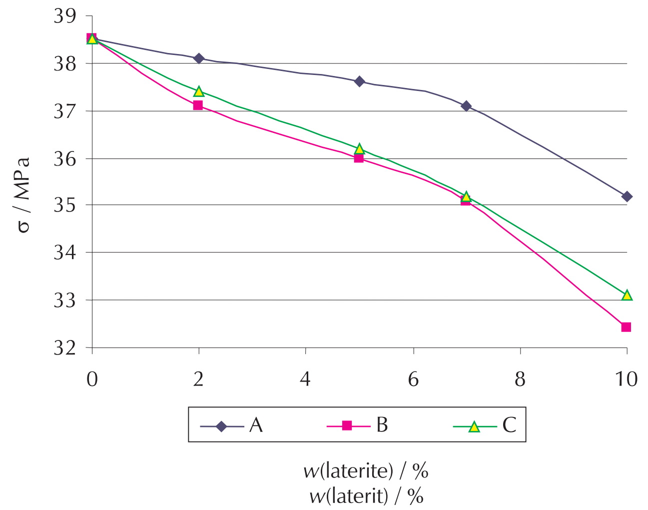
Strength development of cement is influenced by the mineralogy of clinker, pozzolanic reactions, fineness, water demand, etc., of the cement mixtures. Mineralogical phases of the cement which influence the strength development are given in Table 2.

Initially, the compressive strength of the cement is decreased at three days for cement blends compared to OPC, due to the fact that the pozzolanic reaction takes place



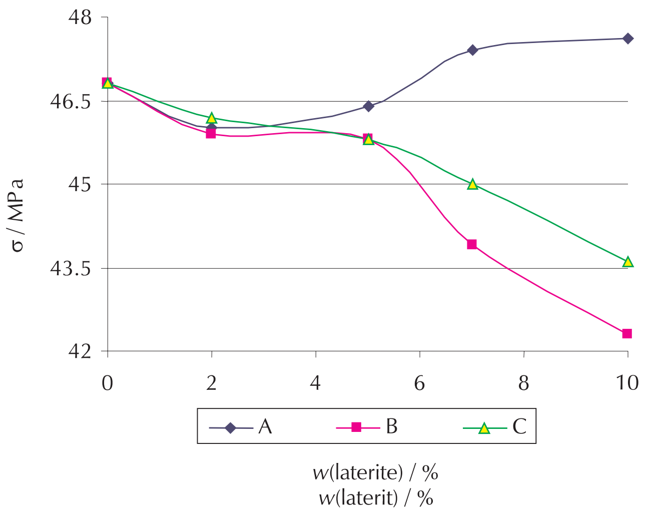
F i g. 5 – *Comparison of Le-Chatelier expansion of OPC and laterite blends*

S l i k a 5 – *Usporedba ekspanzije smjesa OPC-a i laterita po Le Chatelieru*



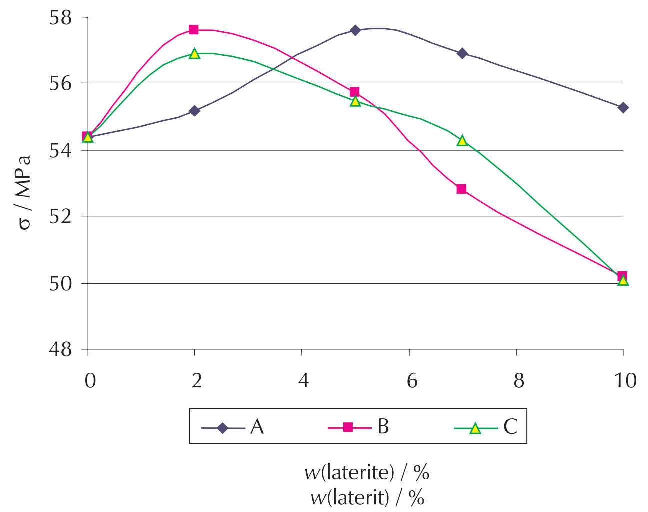
F i g. 6 – *Comparison of 3 days compressive strength of OPC and laterite blends*

S l i k a 6 – *Usporedba trodnevne tlačne čvrstoće smjesa OPC-a i laterita*



F i g. 7 – *Comparison of 7 days compressive strength of OPC and laterite blend*

S l i k a 7 – *Usporedba sedmodnevne tlačne čvrstoće mješavine OPC-a i laterita*



F i g. 8 – *Comparison of 28 days compressive strength of OPC and laterite blends*

S l i k a 8 – *Usporedba tlačne čvrstoće mješavine OPC-a i laterita nakon 28 dana*

slowly at the beginning but with the passage of time the rate of pozzolanic reaction increased.

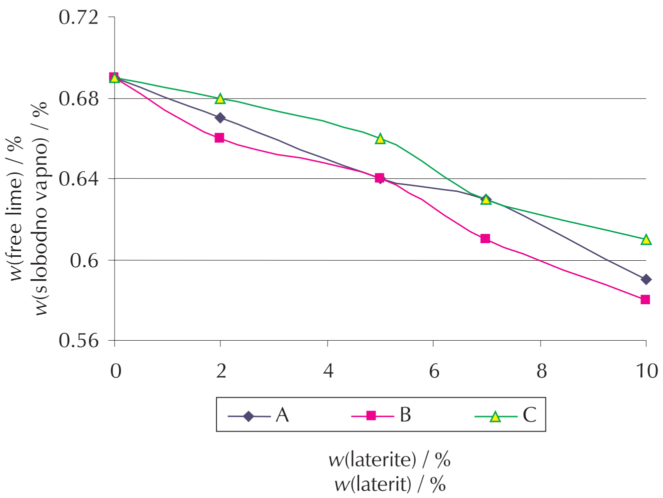
Laterite A (high iron) shows greater compressive strength than laterite B (low alumina) and laterite C (high alumina). Maximum compressive strength is achieved by the addition of 5 % laterite A then other blends, but even these results are in prescribed limits for all as per ASTM C-150-04[24] up to replacement level of 10 % (Figs. 6, 7, and 8).

Free lime

Free lime is an important factor for depicting the expansion of cement. Free lime directly relates to expansion. As the replacement level for all the laterites is increased, free lime is decreased because laterite samples contain no free lime (Fig. 9).

Conclusions

It can be indicated that laterite could be used as SCM or for producing blended cement at the tested replacement level conveniently. Unlike other SCMs, laterite is not a by-product, which means its engineering values are well controlled. Therefore, using Laterite should promise some advantages compared to other cement replacement materials. Some problem with laterite as SCM includes its color, which is mostly red or brownish i.e. when the high percentages of laterite would be used it will slightly change the color of the blended product. In this regard, studies are needed to overcome this problem. The performance of laterite cement will be compared to the cost of laterite to determine whether laterite is worthy of being developed as a new cement replacement material, while in Pakistan laterite is many times cheaper than clinker at the point of production.



F i g. 9 – *Comparison of free lime of OPC and laterite blends*
S l i k a 9 – *Usporedba slobodnog vapna u smjesi OPC-a i laterita*

List of symbols and abbreviations
Popis simbola i kratica

Δd – Le-Chatelier expansion, mm
– ekspanzija cementa po Le Chatelieru, mm

m – mass, g
– masa, g

s_{Blaine} – Blaine specific surface area, $cm^2\ g^{-1}$
– specifična površina određena metodom po Blaineu, $cm^2\ g^{-1}$

t_f – final setting time, min
– konačno vrijeme vezanja, min

t_i – initial setting time, min
– početno vrijeme vezanja, min

w – mass fraction, 1, %
– maseni udjel, 1, %

σ – compressive strength, MPa
– tlačna čvrstoća, MPa

A – high iron laterite
– laterit s visokim udjelom željeza

A.M. – alumina modulus
– modul glinice

B – low alumina laterite
– laterit s niskim udjelom glinice

C – high alumina laterite
– laterit s visokim udjelom glinice

C_2S – dicalcium silicate, Ca_2SiO_4, $2CaO \cdot SiO_2$
– dikalcijev silikat, Ca_2SiO_4, $2CaO \cdot SiO_2$

C_3A – tricalcium aluminate, $Ca_3Al_2O_6$, $3CaO \cdot Al_2O_3$
– trikalcijev aluminat, $Ca_3Al_2O_6$, $3CaO \cdot Al_2O_3$

C_4AF – calcium aluminoferrite, $Ca_2(Al, Fe)_2O_5$, $2CaO \cdot xAl_2O_3 \cdot (1-x)Fe_2O_3$
– tetrakalcijev alumoferit, $Ca_2(Al, Fe)_2O_5$, $2CaO \cdot xAl_2O_3 \cdot (1-x)Fe_2O_3$

LSFc – lime saturation factor for cement
– faktor saturacije vapnenca za cement

OPC – ordinary Portland cement
– obični portland-cement

S.M. – silica modulus
– silikatni modul

SCM – supplementary cementing materials
– dodatni cementni materijal

XRD – X-ray Diffraction
– difrakcija rendgenskih zraka

References
Literatura

1. *P. K. Mehta*, Studies on blended cement containing Santorin earth, Cem. Concr. Res. **11** (1981) 507–518.
2. *P. K. Mehta, P. J. Monteiro*, Concrete Micro-structure properties, and Materials, Prentice Hall, Englewood Cliffs, New Jersey, 1993.
3. *P. K. Mehta*, Role of pozzolanic and cementious materials in sustainable development of the concrete industry, ACI SP-178, Farmington Hills, Mich, (1998) 1–25.
4. *P. K. Mehta*, Greening of concrete industry for sustainable development, Concr. Int. **21** (2002) 23–28.
5. *V. M. Malhotra*, Making concrete greener with fly ash, Concr. Int. **21** (1999) 61–66.
6. *R. J. Detwiller, J. I. Bhatty, S. Bhattacharja,* Supplementary cementing materials for use in blended cements, PCA Research and Development Bulletin RD112T, 1996.
7. *L. Turanli, B. Uzal, F. Bektas*, Effect of material characteristics on the properties of blended cements containing high volumes of natural pozzolans, Cem. Concr. Res. **34** (2004) 2277–2282.
8. *N. Bouzoubaâ, M. H. Zhang, A. Bilodeau, V. M. Malhotra*, Laboratory-produced high-volume fly ash blended cements: physical properties and compressive strength of mortars, Cem. Concr. Res. **28** (11) (1998) 1555–1569.
9. *A. Olugbenga, O. Kolapo, O. Oludare, O. Abiodun*, A study of compressive strength characteristics of laterite/sand hollow blocks, Civil Engineering Dimension **9** (2007) 15–18.
10. *A. K. Kasthurba, M. Santhanam, H. Achyuthan*, Investigation of laterite stones for building purpose from Malabar region, Kerala, SW India – chemical analysis and microstructure studies, Construction and Building Materials **22** (2008) 2400–2408.
11. *Committee on the Status and Research Objectives in the Solid-Earth Sciences*, *National Research Council,* Solid Earth Sciences and Society. Ch.1 (Global Overview). National Academies Press, 1993.
12. *A. H. Usmani*, A summarized note on Laterite deposit of Ziarat area, Sibi District, Geological Survey of Pakistan. I.R No. **257** (1969).
13. *S. H. A. Shah*, The laterite band of Ziarat, Sibi and Loralai districts, Baluchistan, Pakistan, Geological Survey of Pakistan. Record No. **37** (1976).
14. *R. Khan, H. Hussain, M. Saleem*, Cement raw material around Muzaffarabad Azad Kashmir. Geological Survey of Pakistan. I.R. No. **225** (1984).
15. *A. G. J. Johannes, D. Creutzberg*, Laterites: concepts, geology, morphology and chemistry. Wageningen, Netherlands: International Soil Reference and Information Center, 1994.
16. ASTM C0204-00, Test Method for Fineness of Hydraulic Cement by Air-Permeability Apparatus, 2000.

17. ASTM C0187-04, Test Method for Normal Consistency of Hydraulic Cement, 2004.
18. ASTM C0191-04B, Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle, 2004.
19. ASTM C0109M-02, Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens, 2002.
20. ASTM C0114-05, Test Methods for Chemical Analysis of Hydraulic Cement, 2005.
21. BS EN 196-3, Methods of testing cement. Determination of setting times and soundness, 2005.
22. *B. Yılmaz, N. Ediz,* The use of raw and calcined diatomite in cement production, Cement & Concrete Composites **30** (2008) 202–211.
23. BS EN 197-1, Cement. Composition, specifications and conformity criteria for low heat common cements, 2000.
24. ASTM C150 / C150M – 04 Standard Specification for Portland Cement, 2004.

SAŽETAK

Svojstva cementa koji sadrži laterit kao dodatni cementni materijal

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Posljednjih godina od sve je veće važnosti oporaba različitog industrijskog otpada, nusproizvoda ili drugih materijala, primjerice: mljevena granulirana šljaka visokih peći, pirogeni SiO_2, lebdeći pepeo, vapnenac, prašine iz peći i sl. Provedeno je istraživanje svojstava laterita kao dodatnog cementnog materijala (eng. *Supplementary Cementing Materials* – SCM). Istraživanjem je obuhvaćeno mjerenje tlačnih čvrstoća i drugih svojstava miješanog cementa koji sadrži različite udjele laterita. Maseni udjel laterita u miješanom cementu iznosi 2 %, 5 %, 7 % i 10 %, a ispitan je učinak triju kemijski različitih laterita na fizička i kemijska svojstva miješanog cementa kao što su vrijeme vezanja, ekspanzija po Le Chatelieru, gubitak žarenjem, netopljivi ostatak, slobodni CaO te osobito tlačna čvrstoća cementnih kocki ispitanih nakon 3, 7 i 28 dana. Iz rezultata je vidljivo poboljšanje tlačne čvrstoće miješanog cementa u odnosu na referentni cement (eng. *Ordinary Portland Cement* – OPC).

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