Construction and Building Materials 176 (2018) 271–282

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of using colemanite waste and silica fume as partial replacement on the performance of metakaolin-based geopolymer mortars

Mucteba Uysal [a], Mukhallad M. Al-mashhadani [b], Yurdakul Aygörmez [b,*], Orhan Canpolat [b]

[a] Istanbul University, Engineering Faculty, Civil Engineering Department, Avcilar Campus, Istanbul, Turkey
[b] Yildiz Technical University, Faculty of Civil Engineering, Civil Engineering Department, Davutpasa Campus, Istanbul, Turkey

HIGHLIGHTS

- Colemanite waste and silica fume were used as partial replacement with metakaolin.
- Abrasion resistance, strength properties and physical characteristics were investigated.
- The included materials were found to improve the manufactured samples.

ARTICLE INFO

Article history:
Received 22 February 2018
Received in revised form 13 April 2018
Accepted 5 May 2018

Keywords:
Geopolymer
Metakaolin
Colemanite
Silica fume
Polypropylene fibers
Abrasion resistance

ABSTRACT

In this work, metakaolin was partially replaced with two waste materials and the effect of adding those materials on the behavior of the resulted geopolymer composites was investigated regarding physical properties. A comparison was then made between non-fibrous samples and polypropylene fiber reinforced ones in terms of ultrasonic pulse velocity, abrasion resistance, flexural and compressive strength tests together with scanning electron microscopy (SEM) and XRD analyses. In general, results revealed the fact that replacement materials proved to be beneficial. When compared to control sample, colemanite and silica fume samples yielded an improvement of 14.61% and 29.44% in flexural strength, 2.02% and 11.48 in compressive strength, 10.59% and 20% in abrasion resistance. Addition of polypropylene fibers generally helped in improving flexural strength and abrasion resistance of the samples. Microstructural analysis showed a good degree of geopolymerization of the resulted matrix. Colemanite represents a potential usable material in the geopolymer technology especially in Turkey which possesses the world's largest boron reserves.

1. Introduction

The increasing green house gas emissions are nowadays considered among the most effective criterion concerning global warming phenomena. Carbon dioxide is one of the major gases in this concern, CO_2 emissions represent almost 7% of the those emissions worldwide. Cement industry, as a main CO_2 emission reason, is not classified as an eco-friendly fabrication process. To transform the construction industry into the green phase of application, cementitious binders were partially or fully replaced with waste materials and industrial by-products, so many researchers aimed to scrutinize a green alternative through fabricating various binding systems with less or no Portland cement.

Metakaolin – which is described as one of the main pozzolanic materials that are used in geopolymer technology – is a de-hydroxylated form of the clay mineral kaolinite [1] and the main components of metakaolin are amorphous Al_2O_3 and SiO_2 and as a valuable admixture. Metakaolin is considered nowadays as one of the successive main components of the geopolymeric matrix due to the rapid strength gain and the good bonding mechanism with the alkaline solutions [2–4]. Davidovits [5] examined several pozzolanic materials as the main component in geopolymer production, his conclusions stated that metakaolin-slag based geopolymers were the best-produced composites in terms of environmental friendliness as well as acceptable mechanical and durability performance.

Pelisser et al. [6] studied the mechanical characteristics of metakaolin geopolymer mortars. Experiments were carried out to determine the modulus of elasticity, hardness, compressive and flexural strength, flexural modulus, and microstructural analysis. Conclusions revealed that geopolymer mortars yielded better results than Portland cement mortars in terms of strength properties and elastic modulus. Additionally, the micromechanical

* Corresponding author.
E-mail address: aygormez@yildiz.edu.tr (Y. Aygörmez).

https://doi.org/10.1016/j.conbuildmat.2018.05.034
0950-0618/

Table 1
Chemical composition of Metakaolin, Ground Granulated Blast Furnace Slag, Silica Fume and Ground Colemanite (%).

Chemical analysis,%	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	B_2O_3	L.O.I.
MK	56.10	40.23	0.85	0.55	0.19	0.16	0.51	0.24	–	1.10
GGBS	40.55	12.83	1.10	0.75	35.58	5.87	0.68	0.79	–	0.03
SF	91.57	0.38	0.15	–	0.32	4.05	2.58	0.55	–	1.68
Ground Colemanite	5.00	0.40	0.08	–	27.00	3.00	–	0.50	40.00	25.00

Table 2
Properties of investigated fibers.

Fiber Type	Length (mm)	Diameter (μm)	Specific Gravity	Nominal Tensile Strength (Mpa)	Aspect Ratio
PP	12	0.0075	0.91	750	1600

Table 3
Mixing percentages of geopolymer mortar (%).*

Mix ID	Replacement ratio	MK
MK/MK-PP	–	100
10 SF/10 SF-PP	10	90
20 SF/20 SF-PP	20	80
30 SF/30 SF-PP	30	70
40 SF/40 SF-PP	40	60
10 C/10 C-PP	10	90
20 C/20 C-PP	20	80
30 C/30 C-PP	30	70
40 C/40 C-PP	40	60

* *Notes:* 1. In case of fiber reinforced mixes (e.g. MK-PP) the fiber volume fraction was 0.8%. 2. The symbolling of the mixes was as follows: MK for Metakaolin, SF for silica fume, C for colemanite waste, and PP for polypropylene fibers. Numbers (10, 20, 30, 40) refer to the replacement ratio.

properties of both geopolymer and ordinary Portland cement mortars showed a similar behavior, however, geopolymer mortars showed better deformation capacity and tensile strength.

Rovnaník [7] carried out tests on the effect of curing temperature on the hardening development of metakaolin-based geopolymer structure, he aimed to analyze the effect of curing temperature (10, 20, 40, 60 and 80 °C) and time on the compressive and flexural strengths, pore distribution and microstructure of alkali-activated metakaolin material. The study revealed a relationship between the increasing pore size and cumulative pore volume with rising temperature, which in turn affected the mechanical properties. It was also concluded that monitoring the reaction process is possible by means of Infrared Spectroscopy test.

Zhang et al. [8] investigated an experimental work about geopolymer binders composing of metakaolin and fly ash blend as a precursor, specially developed for fire resistance applications. They conducted bending and compression tests were conducted at ambient temperature and after exposure to high temperatures. Development of an optimum MK-FA mix was possible according to the results from the mechanical properties and thermogravimetric analysis. An MK-FA based geopolymer was then considered a possible alternative to conventional Portland cement in practical construction categories.

Lahoti et al. [9] evaluated the effect of Si/Al (molar ratio), water/solids (mass ratio), Al/Na (molar ratio) and H_2O/Na_2O (molar ratio) on the compressive strength of metakaolin-based geopolymers. The research findings revealed that Si/Al ratio is the most significant parameter followed by Al/Na ratio and unlike ordinary Portland cement system, water/solids ratio is not the chief factor governing the strength of metakaolin-based geopolymers.

Since the properties of the geopolymeric matrix can be changed according to many factors such as changing mix proportions, following different curing procedures, changing main or filling materials content, examining different systems of chemical solutions, various research attempts were carried out in order to identify the best matrix composition in terms of the aforementioned criterion.

Burciaga-Díaz et al. [10] analyzed the effect of the curing temperature on the long-term properties and reactions of silicate-activated slag-metakaolin binders. Cubic specimens were permanently cured at 20 °C, 60 °C, and 70 °C to 520 days to evaluate the compressive strength and microstructural composition. Curing of fresh pastes at elevated temperatures helped to accelerate the strength development at early ages but in the long term, curing at 20 °C is more beneficial.

M. Rostami, K. Behfarnia [11] investigated the effect of substituting the slag with silica fume on compressive strength and permeability of alkali-activated slag concrete. The results showed silica fume existence could increase compressive strength and reduce the permeability of alkali-activated slag concrete and water curing was the most appropriate type of curing.

Sukontasukkul et al. [12] examined the influence of steel and polypropylene fibers addition on the flexural performance of fiber-reinforced geopolymer. As a general conclusion, hybridization of steel fiber could improve the flexural response, toughness, and residual strength of polypropylene fiber reinforced geopolymer. Both the load dropping and second peak are found to improve almost instantaneously. The toughness and residual strength also developed gradually the increasing steel fiber content.

Because the current research interests focus on sustainability and replacement resources, different waste materials as a partial replacement in both cementitious and geopolymeric matrices were used in this concern. Boron can take different forms such as tincal, colemanite, kernite, ulexite, pandermite, boracite, szaibelyite and hydroboracite, the simplest form of boron compounds are boron oxide (B_2O_3) and boric acid (H_2BO_3) and when it is found with calcium, it is called as colemanite, with calcium-sodium it is called as ulexite and when it is bonded with sodium, it is called as "borax" [13]. Colemanite waste, as one of the most important waste materials, in Turkey, more than 1.72 million tons of boron minerals and compounds have been produced [14]. Many by-products are

Table 4
Geopolymer mortar mixing proportions (g).

Metakaolin	Rilem Sand	Slag	NaOH (12M)	Na_2SiO_3
450	1125	60	150	300