Construction and Building Materials 88 (2015) 175–187

Contents lists available at ScienceDirect

Construction and Building Materials

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

Combined effect of silica fume and expanded vermiculite on properties of lightweight mortars at ambient and elevated temperatures

Fuat Koksal [a], Osman Gencel [b,*], Mehmet Kaya [c]

[a] Bozok University, Department of Civil Engineering, 66000 Yozgat, Turkey
[b] Bartin University, Department of Civil Engineering, 74100 Bartin, Turkey
[c] Sakarya University, Institute of Natural and Applied, 54187 Sakarya, Turkey

HIGHLIGHTS

- We studied effect of vermiculite and silica fume on mortar properties.
- Silica fume increase mechanical properties of mortar.
- Vermiculite increased thermal properties of mortar.
- Silica fume and vermiculite combinations increased durability against elevated temperature.
- Expanded vermiculite turns out to be a good fire resistant material.

ARTICLE INFO

Article history:
Received 4 March 2015
Received in revised form 13 April 2015
Accepted 16 April 2015
Available online 29 April 2015

Keywords:
Vermiculite
Silica fume
Elevated temperature
Lightweight mortar

ABSTRACT

In this study, properties of cement based mortars produced with vermiculite and silica fume were investigated at ambient and elevated temperatures. Physical, mechanical, thermal and micro structure properties of mortars produced were determined. Mortars were produced at 4, 6 and 8 expanded vermiculite/cement ratio (V/C) by volume. Silica fume was used at the ratios of 0%, 5%, 10% and 15% under each V/C ratio. In total, 114 mortar specimens with 40 × 40 × 160 mm were investigated. Specimens were subjected to 300, 600 and 900 °C for 6 h. It was observed that new formulations with silica fume increased both strength and durability at elevated temperatures of mortars with vermiculite. Unit weights of mortars at hardened state range between 1200 and 780 kg/m^3. Water absorption values range between 24.2% and 40.6%. Strengths of mortars vary between 3.9 MPa and 16.4 MPa at ambient temperature. Thermal conductivity coefficient of mortars indicated a decrease depending on V/C ratio of mortar up to 0.257 W/m K which means 58.2% increment in thermal performance. Mortars produced using expanded vermiculite aggregate shows a good performance in terms of preservation of mechanical strength to elevated temperature. This means that expanded vermiculite turns out to be a good fire resistant material.

1. Introduction

Energy efficient buildings are recently one of the most important issues since both economic and environmental factors nowadays are of great importance in the world. Countries focus on increasing energy efficiency of buildings since about one third of overall energy consumed is used in buildings. The need to have more energy efficient buildings leads to develop new materials or improve existing construction materials and lightweight systems [1,2]. Lightweight aggregates such as such as perlite, pumice and expanded clay with cellular or porous structure have been used for producing masonry blocks, wall panels, cladding products and lightweight concretes [3]. Production of lightweight concretes can be achieved in three ways which are using pore maker gassing agents, lightweight mineral aggregates and polymer based plastic granule aggregates [4].

Lightweight concretes present superior properties such as, thermal isolation [5–7], fire/high temperature resistance and so protection [8–13], sound insolation [14–19], strength enough for structural applications and reducing dead load of structure resulting in a decreased cross sections of structural elements and a reduction in risk of earthquake damage [20–22], durability [23–28] etc. Another mineral lightweight aggregate is vermiculite which is widely used.

* Corresponding author at: Faculty of Engineering, Bartin University, Turkey. Tel.: +90 378 223 5360; fax: +90 378 223 5258.
E-mail address: osmangencel@gmail.com (O. Gencel).

http://dx.doi.org/10.1016/j.conbuildmat.2015.04.021
0950-0618/

Nomenclature

V/C	vermiculite/cement
XRF	X-ray florescence
XRD	X-ray diffraction
TG	thermogravimetric
SEM	scanning electron microscopy
CSH	hydrated calcium silicate
P	porosity
W_{ssd}	specimen weight in the saturated surface dry condition
W_d	specimen dry weight
W_w	weight of saturated specimen
S	supersonic wave speed
s	second
d	distance
t	time
m	meter
W/m K	watt/meter Kelvin
ASTM	American Society for Testing and Materials
CEM	cement type
h	hour

Vermiculites are naturally occurring minerals composed of shiny flakes, resembling mica in appearance. They are primarily formed by alteration of micaceous minerals (variable mixtures of different minerals like vermiculite, hydrobiotite and phlogopite) as a result of weathering, hydrothermal action, percolating ground water or a combination of these three factors. It has hydrated aluminum and magnesium silicate. When heated to elevated temperatures up to 650–1000 °C, flakes of vermiculite expand as much as 8–30 times with respect to their original size due to conversion of interlayer and structural water to steam [29]. Expanded vermiculite after cooling preserves its new volume with very thin streaks of air between leaves. Particles of expanded vermiculite are viewed as thin plates separated by air gaps. Their shape, color, luster and grain composition are closely related to original raw material. Water absorption capacity of vermiculite increases drastically when the bulk density varies between 64 and 160 kg/m^3 depending on particle size, after exfoliation. As a result, the annealed vermiculite possesses several valuable properties, such as low thermal conductivity, high fire resistance and strong sound absorption. Vermiculite is an effective high temperature (up to 1100 °C) heat isolation material. Materials and products produced using vermiculite are incombustible, biostable and neutral to the action of acids and have stable strength with time and resistance to deformation. These facts make worthwhile the application of vermiculite in construction and simultaneously heat isolation and sound absorption materials. Using effective high temperature and thermal isolation materials allows reducing material capacity of constructions. Expanded vermiculite has very low specific gravity. It can be used in production cement and polymer based composites [30,31]. Vermiculite ores are mostly found in South Africa (41%), USA (21%) and China (21%). In Turkey, totally 5.2 Mt reserve of vermiculite is reported by Mineral Research & Exploration General Directorate [2].

As mentioned above, there are many studies on lightweight aggregates such as pumice, perlite, expanded clay, expanded polystyrene and their usages in lightweight systems. However, studies about the use of vermiculite are limited. Schackow et al. [32] investigated the effect of air-entraining and superplasticizer admixtures on mechanical and thermal properties of lightweight concrete produced by replacing sand with expanded polystyrene and vermiculite. They observed that while addition of air-entraining admixtures decreases unit weight and increase thermal performance of concrete, strength decreases. Silva et al. [33] studied properties of mortar with water-retaining and air-entraining agents and fillers, vermiculite and perlite. Incorporation of perlite and vermiculite as filler into mortar decreases mechanical properties of mortar due to lack of cohesion. Also, perlite and vermiculite are responsible for voids and higher capillarity, water demand and shrinkage. Mladenovic et al. [34] studied mortar produced with expanded vermiculite, expanded clay, expanded glass and perlite regarding their durability like alkali silica reaction, and observed that expanded vermiculite did not exhibit any potential alkali silica reaction. Formosa et al. [35] studied behavior of vermiculite and magnesium by-product as aggregates in the production of fire proof mortars, and reported that mortar with magnesium by-product and vermiculite had effects. Koksal et al. [36] investigated properties of cement based bricks containing expanded vermiculite modified with styrene acrylic ester copolymer, and concluded that polymer–cement and vermiculite–cement ratios on properties of brick were are importantly exposed. In these studies, compressive strength seems low.

Sutcu [2] investigated properties of brick mixtures containing vermiculite at different proportions. Vermiculite addition increases porosity resulting in an increased thermal performance. And the brick samples produced with vermiculite addition could be used as an insulating material in construction applications. Gencel et al. [37] used expanded vermiculite in production of lightweight gypsum composites. While compressive strength of composite decreases thermal conductivity values decreases by depending on vermiculite content in the composites. Abidi et al. [38] studied thermo-mechanical performance of plaster composite panels with perlite and vermiculite for thermal insulator and fire passive protection in building construction, and observed that thermal performance and fire resistance increased. Marties et al. [39] investigated mechanical reinforcement and thermal insulator properties of gypsum based composites produced with mineral products such as vermiculite, mica, glass fibers. Plaster is used as a matrix and mineral products (vermiculite, mica, glass fibers) are added as lightweight additives mechanical reinforcement and thermal insulator, and reported that both particles size distribution and amounts of additives had an effect on the mechanical properties and fire resistance. Melo et al. [40] used vermiculite in gypsum composite for energy efficiency in building, and reported that the usage of vermiculite in gypsum composite and plaster increased thermal performance. But, it is well-known that the main disadvantage of gypsum plaster is its brittleness at room temperature and its poor resistance to crack opening and propagation when it is subjected to fire conditions.

Another aspect in development and improvement of cement based composites is usage of mineral admixtures such as fly ash and silica fume etc. In this respect, there are numerous studies reported in literature. However, cement based composite products such as concrete and mortar containing combination of expanded vermiculite and silica fume have not been reported as understood from literature survey above. This work aims to develop mortars formulated with both vermiculite and silica fume which is industrial by-product obtained from silicon or silicon ferrosilicon alloy industries and investigate the effect of elevated temperatures on physical, mechanical and thermal properties of them.