Incorporation of glass particles in high-performance mortars

M. Stefanidou[1], E. Anastasiou[1], Mantziou O[1]. Mpougla E[1]. Vasiliou E[1].Konti P.D.[1] Antoniadis K. [2]

[1]Laboratory of Building Materials Civil Engineering Department, AUTH, Greece e-mail: stefan@civil.auth.gr, tel:2310995635 fax: 2310995699

2 Laboratory of Thermophysical Properties & Environmental Processes Chemical Engineering Department AUTH, Greece

Abstract

Mortars started to be used as protective coatings (renders) during the Neolithic period (8th millenium BC) and since then they constantly contributed to the longevity and durability of construction. Diachronically, their manufacture was based on the available raw materials serving economy and ecology values, while their application technology was aiming to protect structures by increasing their resistance to weathering. Through centuries, the demands in construction were increased as functional, aesthetic, economic and insulating criteria had to be fulfilled. Into this frame, renders had to play a malty-phase role. In the present work a series of mortars were produced based on white cement and lime as binders and three different aggregate types (river sand, glass spheres available at the market and recycled glass particles from broken bottles, laboratory produced) were tested as aggregates in order to produce a render with improved properties. Microstructure, physical- mechanical properties and thermal conductivity were measured in the produced mortars in order to explore the possibility of replacing sand from natural resources, with glass particles. The results indicate that a more porous structure is achieved in the case where glass particles are used, improving the thermal behavior of the mortars.

Keywords: renders, recycled glass, microstructure, thermal conductivity

Introduction

Mortars are diachronic building materials which date from the first effort of human beings to build a dwelling. They are mainly used for bonding pieces of solid pieces of stone or brick, for protective or decorative covering or for making floors or substrates. The easy preparation of the mortar mixture, its plasticity and its property to harden with time makes it an indispensable building material up to nowadays [1]. The mortar mixture consists of a binder, aggregates and water. The use of inorganic or organic additives is also known as an effort to improve mortar’s performance or properties. With reference to energy saving in building projects, the science of building materials has been directed towards creating materials with improved environmental profile by using the available expertise. The irrational use and the large consumption of non renewable energy resources, has lead not only to their depletion, but also to dramatic environmental problems. The need for energy preservation is highly evident in the construction sector, which accounts for 40% of the energy consumption in the European Union [2] [3]. The study of the technological evolution of mortars reveals a great source of information regarding the type and proportions of raw materials used (binders, aggregates, additives, admixtures), their application technology, as well as their resistance to ageing and environmental factors [4]. The size distribution and the shape of a mortar’s aggregates influence the amount and size of the voids within it, which affects its performance [5] [6]. A lower voids content means that less binder and water are required, which has the beneficial effect of reducing shrinkage and has an influence on various properties of mortars, in both the fresh and the hardened state. Addition of aggregates to a binding system has proved to confer technical advantages as they contribute to volume stability, durability and structural performance. Apart from the different type of aggregates as their mineralogy is concerned, the volume content in the mixture, the maximum size and their gradation influence the structure of a binder–aggregate mixture [7]. Properties such as rheology, strength, shrinkage, porosity are strongly based on the type, the ratio, and the gradation of the aggregates [8]. Sands of different origins have been used in mortars and different flow ability, strength and stiffness have been recorded [9] [10]. Additionally, the increased water demand was recorded in cases where angular in shape aggregates have been used, and the binder-aggregates transition zone in those cases improved even if porosity had increased [11] [16]. All the sands that are characterized as suitable for use should be of selected maximum size, present an even granulometry and be free of organics and soluble salts. In order to improve the environmental fingerprint of mortars different approaches have been made. Sand from construction and demolition waste in repair mortars has been tested showing dense structure of the lime mortars due to the reaction of lime with Si and Al compounds of the fine aggregates [12]. In relative studies trying to incorporate glass particles in renders it was concluded that mortars with 10%, 15% and 20% incorporation fine glass aggregates, substituting parts of natural sand, perform better than the reference mortar [13]. This improvement was attributed to the filler effect and a possible pozzolanic effect prompted by the glass fines. The application of red clay waste as aggregate for manufacturing mortars resulted in a compression strength increase of the mortars, due to a microfiller effect of the super fines and to a pozzolanic effect presented by some components of crushed debris. Additionally, a reduction of their capillarity as a result of the increase in compactness due to a microfiller effect was observed [14].

The present research presents the modifications recorded in mortars produced by natural sand, glass spheres and glass particles, all of the same gradation. The substitution of the natural sand was 100%. The physical, mechanical and microstructure properties of the produced mortars were tested at the age of 28 days. Also, the criterion of producing materials of low cost, at a close distance from the current production line, with improved properties was also considered.

Materials and Methods

The physical, mechanical and structural properties of a series of renders prepared in the Laboratory of Building Materials of Aristotle University of Thessaloniki using cement and combination of cement and lime as binders and river sand and two types of recycled glass as aggregates were measured, with the ultimate goal of achieving optimum performance renders.

Prismatic (40x40x160 mm) and cylindrical specimens (5x0.0.5cm) were prepared and their physical, mechanical and water proof properties were studied as well as an estimation of their thermal conductivity factor (λ) was performed. Six series of mortars were prepared using white cement and combination of white cement and hydrated lime (Type N) as binders and different aggregates in binder/aggregate proportion 1/ 1.5 by weight. White cement (CEM I42.5N) was chosen in order not to induce color changes and also due to its alkali-free content in order to reduce pathology problems [15]. Lime (type S according to EN 459-1) was added as substitution of a part of cement in some compositions, a technique often used in construction, in order to increase the plasticity of the mixtures. The aggregates in the first mortar series were silica sand of 0-0.5mm size. In the second series the sand was totally substituted by glass fragments which were laboratory produced by milling bottles. The sieved material used was 0-0.5mm and in the third series of mortars the aggregates used were glass spheres of 0-0.5mm (Poraver). These spheres are industrially manufactured and are composed of small and light spheres with tiny pores from recycled glass (Fig.1). In Table 1 the mortar compositions are illustrated.

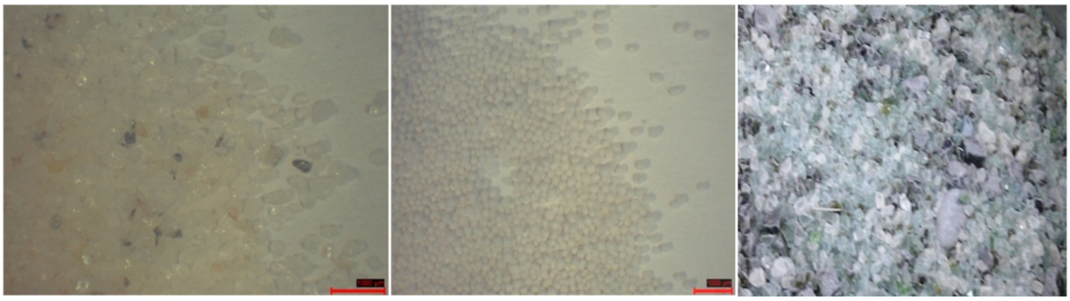

Fig.1Silica sand (left), glass spheres (centre) and glass particles (right) under stereoscope

Table1. Composition of the mortars by weight

	White cement	Lime	Silica sand	Broken glass	Glass spheres	N/K	Workability (cm)
A1	1		1.5			0.55	15.2
A2	0.75	0.25	1.5			0.57	15.3
B1	1			1.5		0.62	15.9
B2	0.75	0.25		1.5		0.70	16.0
G1	1				1.5	0.92	14.1
G2	0.75	0.25			1.5	0.94	14.6

The mechanical properties were tested based on the EN 1015- 11:1999 regulation. The porosity was measured according to the RILEM CPC11.3 methodology based on water absorption under vacuum and the capillary coefficient was measured according to EN 1015-18:2002. The thermal conductivity (λ) was measured using the commercial equipment Quickline 10 (Anter Corporation, USA). The Quickline-10 uses the ASTM E1530 guarded heat flow meter method in order to measure the thermal conductivity of solid samples using cylindrical specimens. Water contact angle measurements were conducted using distilled water by Kruss G10 Goniometer-Optical Surface Tension /Contact Angle meter instrument. Contact angle was calculated by the static drop method. Roughness measurements of the surface were carried out using a Mitutoyo profilometer and Ra values were recorded which are used widely as one-dimensional roughness parameter and concern the arithmetic average of the absolute values (Degarmo et al. 2003). Microstructure observation was performed with stereoscope (Leica Wild M10) and polarized microscope (Leitz Laborlux12 POL S) assisted by image analysis (ProgRes), as well as Scanning Electron Microscopy (JEOL840A JSM).

Results and Discussion

At 28 days the mechanical and physical properties were reported and accumulated in Table 2. The results indicate that there is a small increase in water demand when lime is added in the binding system in all the mortar series (A2 in relation to A1, B2 in relation to B1 and G2 in relation to G1). Keeping the same workability, the water demand is high when the silica sand is substituted both by glass particles and glass spheres (composition G) where the need is even higher for the rounded particles. This can be owned mainly to their texture and porosity properties. The water addition in series B and G can be the main reason for the reduction of the compressive strength in compositions B1 and G1 in relation to composition A1 (in this last case the strength decrease reaches 60%) and the decrease is even higher when lime is used (composition G2) (Table 2). The strength reduction is accompanied by the increase of porosity as expected [17]. The porosity is high when glass is used instead of silica sand. This can be attributed to the porous nature of glass spheres and to the cracks developed around the particles of broken glass as microscopic analysis showed. The highest porosity values were recorded for the G series mortars and this is in accordance with the porous structure recorded by SEM analysis (Fig.3). Rounded porous of different diameter prevail into the structure. These pores do not seem to communicate as is also recorded by the capillary coefficient parameter. In the case of B series the porosity is mainly attributed to the cracks developed around the glass grains (Fig.3b). As the capillary coefficient and the contact angle are concerned, in series A and G the addition of lime in the binding system reduces the absorption capacity indicating that the interconnectivity of the capillary pores is blocked. The reverse is observed in B series where the coefficient is higher in relation to the other mixtures. The capillary coefficient indicates the rate of absorption and not the total absorption volume. The rate of absorption is higher for larger capillary pores.

In relation to the contact angle all the specimens present low values indicating hydrophilic nature of the surface. A small contact angle indicates molecular attraction between the liquid and the substrate. The addition of lime in the binding system further reduces the water drop contact angle due to the high hydrophilic nature of lime (Fig.2). The mixtures of A series though, present the higher values in comparison to the other series (B and G) while the spherical particles of the PORAVER glasses (series G) present extreme hydrophilic nature probably due to their structure.

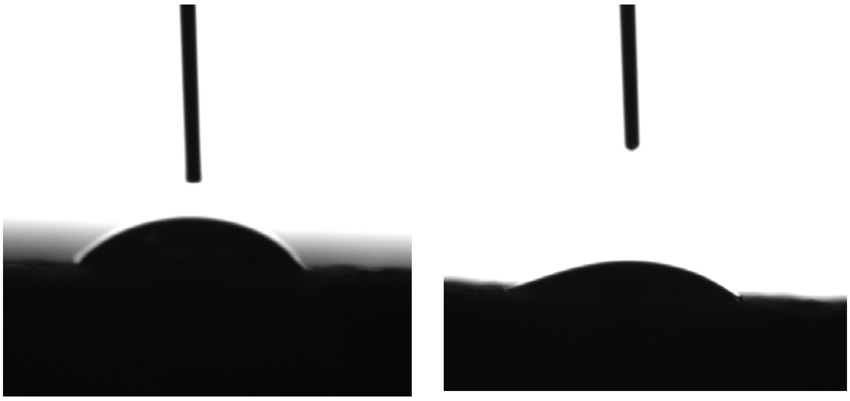

Figure2. Water drop in A1 (left) and G1 samples (right)

The roughness of the specimens (Ra) was also indicative as samples of the G series present the highest roughness while the samples with silica sand have the smoothest surface. The roughness measured by this method had covered an area of $4x4cm^2$ in three specimens for each sample and it can be attributed to the structure achieved and seen by the SEM observation.

From the mortars incorporating glass particles as aggregates it seems that λ values are gradually decreased when broken glass was used and this reduction was even larger when glass spheres were used. The addition of lime in the binding system reduces furthermore the λ values indicating a mortar with insulating properties.

SEM images reveal the good contact of the silica sand with the paste (Fig3a) while in the composition with the broken glass particles there were cracks around them (Fig3b). The porous structure of the specimens with glass spheres is shown in Fig3c. The possibility that the glass would produce alkali-silica reaction (ASR) seems inhibited, as from the SEM analysis no reaction products in the interface zones of all the examined samples were detected. Neither aggregate dissolution nor reaction between the aggregates and the matrix was recorded up to the age of 28 days.

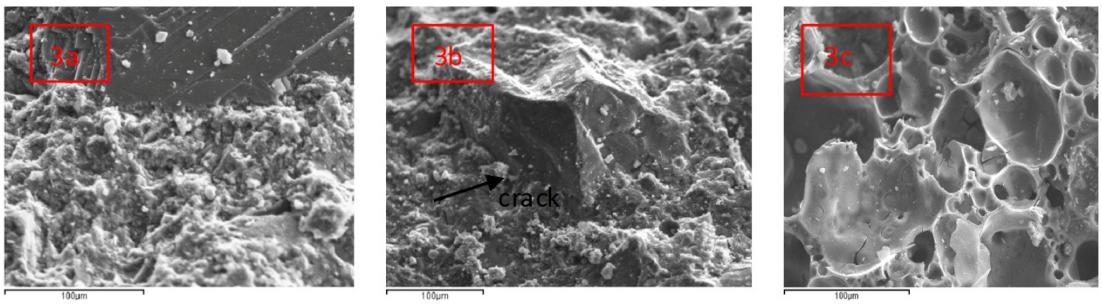

Fig3. SEM images of A sample with strong sand-cement interface (3a), crack in the circumference of a glass grain and the matrix in B sample (3b) and porous structure in C sample (3c)

Table2. Physical and mechanical properties at the age of 28 days

	Comp. strength MPa	Flex. Strength MPa	Porosity %	Capillary coefficient $g/cm^2min^{0.5}$	λ (W/m K)	Contact angle (°)	R(a) mm
A1	25.90	5.71	27.93	0.0124	1.33	85.7	0.082206
A2	19.05	4.56	27.23	0.0050	1.21	72	
B1	22.38	5.16	29.25	0.0196	1.03	38.2	0.124787
B2	12.88	4.69	30.85	0.0221	0.70	36.5	
G1	10.49	3.01	30.39	0.0072	0.57	33.7	0.158151
G2	6.77	2.15	31.93	0.0087	0.42	33.2	

Conclusions

The total substitution of silica sand with recycled glass particles of the same gradation, in mortars based on cement and lime gave interesting results in relation to the performance of the materials. An increased demand in water was recorded in order to achieve the required workability. A more stiff mixture is achieved in mortars containing glass particles in comparison with those containing silica sand. As a consequence, the mechanical properties were reduced and the porosity was higher.

The glass particles of the different origin also introduced different properties in the mortar mixtures. A very porous nature was observed in the mortars containing the glass spheres due to the formation of rounded in shape pores of various diameter. The interconnectivity of the pores is not high and thus the capillary coefficient in low. The induced porosity is probably responsible for the low values of the thermal conductivity (λ) imparting thermal insulating properties. Also, this microstructure is responsible for the high roughness recorded though the water drop analysis, which shows a hydrophilic material.

The glass particles produced in the laboratory, by crashing bottles, were angular in shape. The formation of cracks in the transition zone between the grains and the binder was observed. The porosity recorded in these mortars present interconnectivity and the capillary coefficient was high. The roughness was also higher in relation to the mortars with silica sand.

Keeping in mind that high compressive strength is not required in renders but other properties seem to play a significant role to their performance such as adhesion, the increased roughness recorded in these systems is a positive parameter towards this direction. Additionally, improvement in the performance of mortars with incorporation of fine glass aggregates, in relation to capillary absorption and thermal conductivity relative to a conventional mortar, provides advantages in terms of behaviour/performance and recycling/environment.

The study performed seems to point out valid pathways to improve the performance of render mortars through the incorporation in their composition of glass waste. Therefore, the use of fine recycled glass used as aggregates in masonry mortar manufacturing could be a viable alternative that would support sustainable development in the building sector.

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