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A CASE STUDY ON EVALUATING THE RESIDUAL STRENGTH OF CONCRETE CUBES CAOTED WITH CEMENT BASED PLASTERING MATERIALS WITH EXPANDED PERLITE AND QUARTZ POWDER

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الملخص العربي

تعتبر مخاطر الحريق من الكوارث الجسيمه التي تؤثر علي المنشات و المباني. نتيجة الاستخدام الواسع للخرسانة كمادة بناء, كان لابد من الفهم التام لتاثير الحريق علي خواص الخرسانة و سلوكها. يتميزكلا من ركام البيرلايت المتمدد و بودرة الكوارتز بمقاومة درجات الحرارة المرتفعة. تم طلاء مكعبات من الخرسانة بنوعيين من مواد المحاره التي تحتوي علي ركام البيرلايت المتمدد كركام خفيف وواحده منهم تحتوي علي بودرة الكوارتز كبديل جزئي عن الاسمنت و تم تقييم ادائهم بالنسبة للحريق كدراسة حاله. تم حرق العينات عند درجات حرارة 550, 850 و 1000 درجة مئوية و تم قياس مقاومة الضغط المتبقيه. اظهرت مادة المحارة التي تتكون من خليط من ركام البيرلايت المتمدد و بودرة الكوارتز تحسن في مقاومة الضغط المتبقية للعينات.

Abstract

Fire hazards is generally evaluated to be one of the most dangerous risks to the buildings and structures. The wide use of concrete as a construction material resulted to the high demand and fully understanding the impact of fire on its properties and behavior. Expanded perlite aggregate and quartz powder are known for their high resistance at elevated temperatures. As a case study, concrete cubes were coated with 2 plastering materials composed of expanded perlite as a lightweight aggregate and one of them contains quartz powder as a partial replacement of cement and their fire behaviors were evaluated. The specimens were subjected to 550, 850, and 1000°C and their residual compressive strengths were measured. The coating material with the mixture of expanded perlite and quartz powder showed a considerable improvement in the residual compressive strength of the samples.

1. Introduction

Fire resistance is one of the crucial properties of any material. It is defined as the blockage of excessive heat or flames through the materials under the operating conditions. When talking about construction elements, it is defined as the ability of the building element to continue its structural function and to confine the fire for a defined period of time **[1]**. Concrete is a widely used material for construction, it reacts quite well at high temperatures because of its incombustibility and low thermal diffusivity **[2]**. When concrete is exposed to high temperatures, reduction in the mechanical properties such as compressive strength and modulus of elasticity can be recognized due to changes in concrete physical and chemical properties **[3,4]** accompanied by changes in its microstructure **[5]**. Increasing the fire resistance of concrete elements can be achieved by 2 methods. First, it can be achieved by applying changes to the composition of concrete from the cement type, aggregate type, W/C ratio, additives, and utilization of fibers as the deterioration of the concrete properties is related to its materials **[6]**. Other method is applying insulative coating material with high fire resistance on the concrete elements to maintain their mechanical properties, which we will be studying in this article.

Lightweight aggregate concrete has proved its efficiency in improving the fire resistance. Perlite is a type of lightweight aggregates which is an amorphous volcanic glass with high silica content, and has the unusual property of greatly expanding when heated sufficiently **[7]**. Expanded perlite is formed when perlite is heated to 900-1200°C, which is a lightweight porous material with total porosity that can reach up to 26% of its volume **[8]**. Expanded perlite has been widely used in fire-proofing materials because of its porous microstructure which reduces the internal pressure at high temperatures along with its low thermal conductivity value, so it reduces the heat transfer in the concrete interlayers.

Quartz powder is a chemically inert material at normal temperatures, however at high temperatures it can't be considered completely inert **[9]**. Bakhtiyari and colleagues **[10]** studied the influence of adding quartz powder on the concrete behavior on a small scale. The study showed that quartz powder had a positive effect on the residual compressive strength of the concrete specimens.

In this article, we will be studying the effect of fire on the residual compressive strength of concrete cubes coated with 2 cement-based materials. the first material is composed mainly of cement and expanded perlite as a lightweight aggregate. In the second material, quartz powder was used as a partial replacement of cement with the utilization of expanded perlite also as a lightweight aggregate.

2. Studied materials

The studied materials are ready-mixed cement-based materials. The first material (P1-EP) is a mixture of Portland cement and expanded perlite (EP) as a lightweight aggregate. The second material (P2-EP/QP) is composed of quartz powder (QP) as a partial replacement of

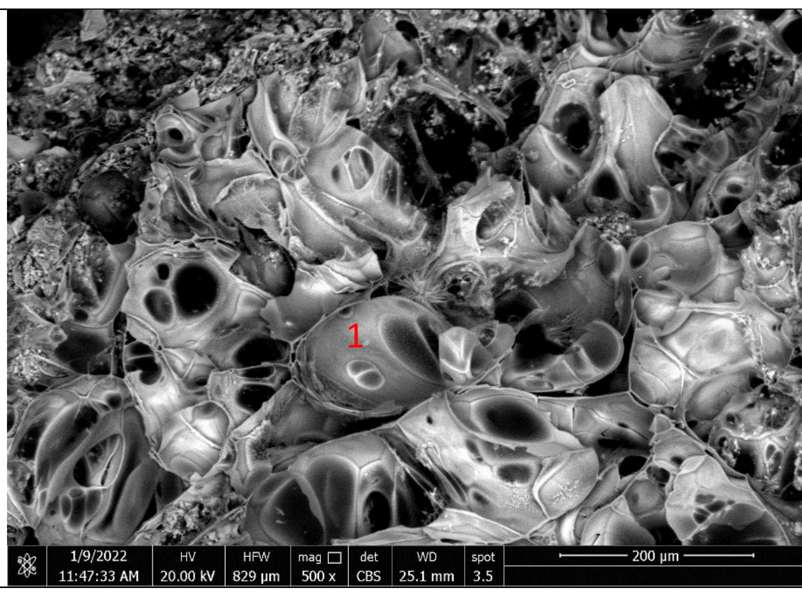
Portland cement and expanded perlite as a lightweight aggregate. The materials were mixed mechanically for 10 minutes with the addition of amount of water approximately equal to the weight of the materials as instructed by the manufacturer as shown in **Figure (1)**. Table **(1)** presents the chemical analysis using XRF analysis of the 2 studied materials. It was observed from the XRF analysis that the main phase of the 2 studied materials is silica, this is attributed to the utilization of expanded perlite aggregate and quartz powder which are rich in silica. P2 showed a slightly higher silica content due to the incorporation of quartz powder in addition to expanded perlite unlike P1 which used expanded perlite only. SEM and EDS analysis were carried out to identify the incorporation of the expanded perlite and quartz powder in the microstructure of the 2 studied materials and the results are shown in **Figure (2)**. The expanded perlite grains appeared as brilliant white grains with trapped bubbles and was confirmed by the high silica content from the EDS analysis points 1 and 3. In the second material (P2-EP/QP) quartz powder appeared as irregular sharp-edged particles with high silica content confirmed by the EDS analysis point 2.

Table (1) Elemental composition of the studied materials

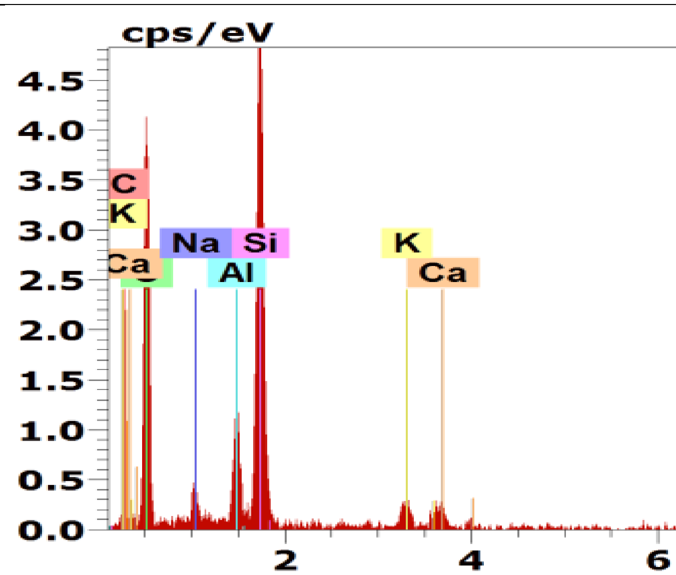
D.N.	P1-EP	P2-EP/QP
SiO_2	54.97	62.50
TiO_2	0.08	0.09
Al_2O_3	7.14	7.05
Fe_2O_3	0.75	0.90
MnO	0.02	0.03
MgO	0.01	0.01
CaO	21.02	14.80
Na_2O	1.35	1.50
K_2O	4.8	4.50
P_2O_5	0.01	0.01
Cl	0.02	0.02
SO_3	1.46	0.95
LOI*	8.37	7.64

***** Loss on ignition

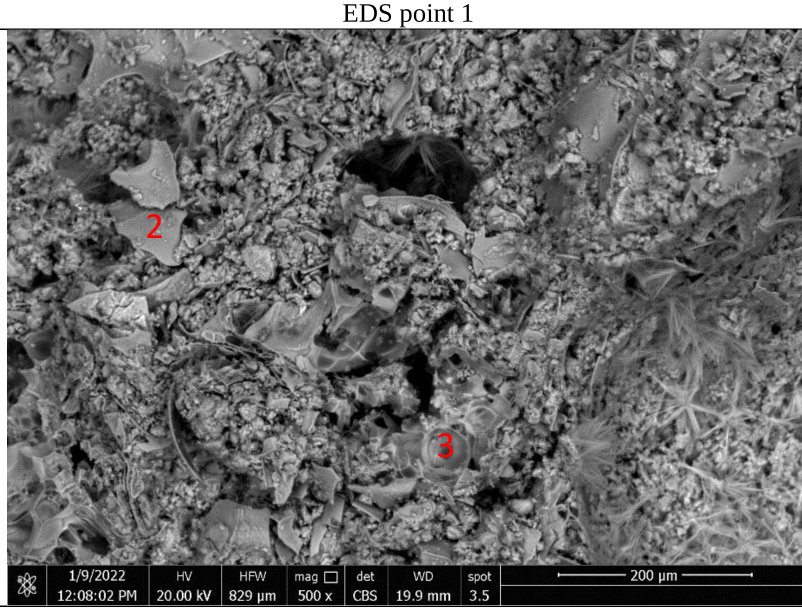
Figure (1) Hydraulic mixing of the materials until reach a homogenous mixture



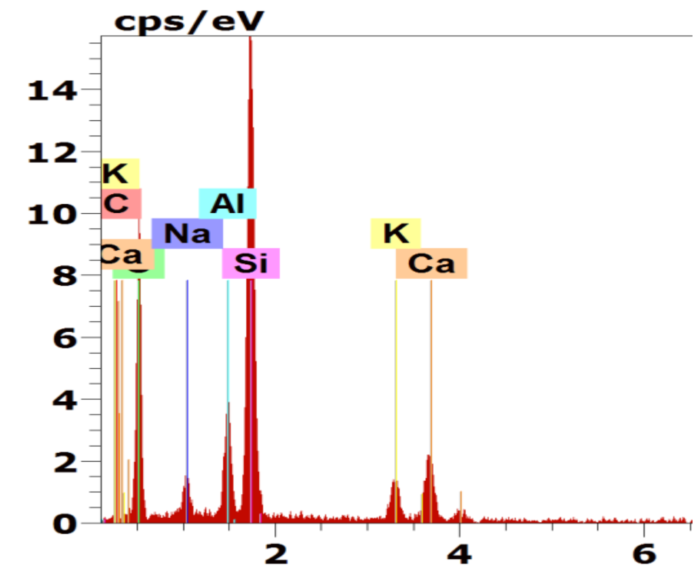
P1-EP



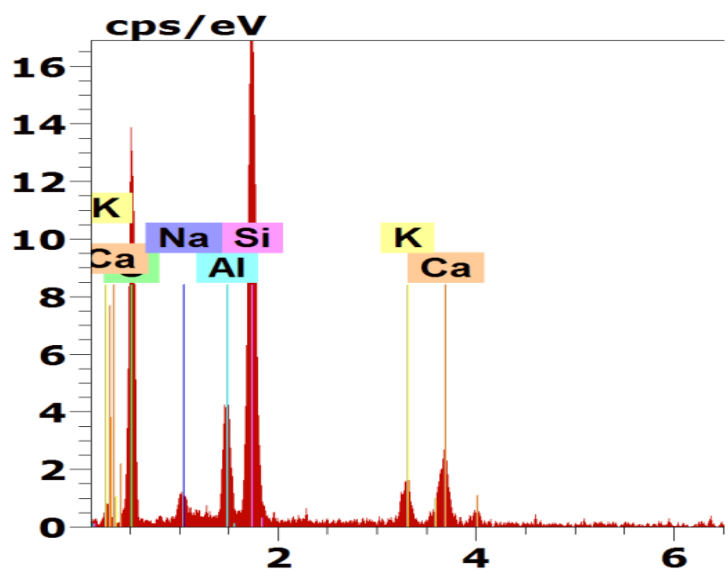
EDS point 1



P2-EP/QP



EDS point 2



EDS point 3

Figure (2) SEM and EDS analysis of the 2 studied materials

3. Experimental program

3.1. Dry bulk density and porosity

Determination of dry bulk density, and porosity was performed according to ASTM C642 **[11]** on specimens of dimensions 50 mm x 50 mm x 50 mm. First, the specimens are dried in the oven for not less than 24 hrs at a temperature of 100 to 110 °C. after removing the specimens from the oven, allow them to cool then determine the mass. Repeat the previous step again until there is no change in the mass of the specimens and this mass is designated (**A**). Place the specimens in a suitable receptacle covered with tap water and boil for 5 h, then allow them to cool for not more than 14 h by natural loss of heat. Surface-dry the specimens by removing surface moisture with a towel and determine the mass which is designated (**B**). Suspend the specimens, after immersion and boiling, by a wire and determine the apparent mass in water. Designate this apparent mass (**C**).

Dry bulk density $= \frac{A}{(B-C)*\rho}$ (gm/cm^3)

% Voids $= (\frac{B-A}{B-C})*100$

Where: ρ… density of water (1 gm/cm^3).

3.2. Thermogravimetric analysis

The thermogravimetric analysis (TGA) was performed by simultaneous thermal analysis (STA) using a TA Instruments SDT Q600 equipment on a powder sample. The heating rate was 10 C/min, from 25 C to 1000 C, in air atmosphere.

3.3. Fire resistance

To study the effect of fire on the compressive strength of concrete, concrete cubes were prepared with dimensions 100 x 100 x 100 mm as shown in **Figure (3)**. The specimens were allowed to cool prior to testing as this would simulate the evaluation of concrete within a structure after a fire. The 2 studied materials in this article were used as coating materials for the concrete specimens with variable thickness 1 cm and 2 cm as shown in **Figure (4).** The specimens were not subjected to any load during heating. The test was carried out 550, 850 and 1000°C for 2 hours according to the standard ASTM E119 **[12]**. At each specified temperature, 3 specimens of each coating thickness (1 cm and 2 cm) were subjected to the fire. Then the specimens were left to cool, and the residual compressive strength was determined.

Figure (3) Un plastered concrete samples

Figure (4) Concrete samples plastered with 1 cm and 2 cm of the studied materials

4. Results and discussion

4.1. Dry bulk density and porosity

The dry bulk density and porosity were determined for the 2 studied materials and the results are shown in **Table (2)**. It can be observed that both materials showed high porosity percentages, this is attributed to the utilization of expanded perlite as a lightweight aggregate which is characterized by its porous structure. However, it is clear that the incorporation of quartz powder in P2-EP/QP decreased its porosity percentage when compared to P1-EP. This is because although quartz powder is considered as an inert material, but it can accelerate the hydration of the clinker component because of its physical effect. This phenomenon results in a denser mix as it increases the growth of calcium silicate hydrate (C-S-H) phase **[13,14]**. The dry bulk density was directly related to the porosity values of the studied materials.

Table (2) Dry bulk density and voids percentage of the studied materials

Property	**P1-EP**	**P2-EP/QP**
Bulk dry density (kg/m^3)	420	492
% Voids	47.2	31.5

4.2. Thermogravimetric analysis

The TGA curves of the studied materials are shown in **Figures (5)** and **(6)**. At approximately, 550°C, material P1-EP showed about 8% loss in its weight higher than material P2-EP/QP which lost approximately 5% of its weight. This is due to the decomposition of $Ca(OH)_2$ which takes place at approximately 500°C into Cao and water and the decomposition of the C-S-H phase which occurs at 450-750°C into C_3S and C_2S since both materials are cement based materials. However, the P2-EP/QP showed lower weight loss than P1-EP since it is composed of quartz powder as a partial replacement of cement which has resistance at elevated temperatures. Both materials showed about 10% loss in their weight at 1000°C, this is attributed to the decomposition of expanded perlite in both materials which is thermally stable up to 900°C.

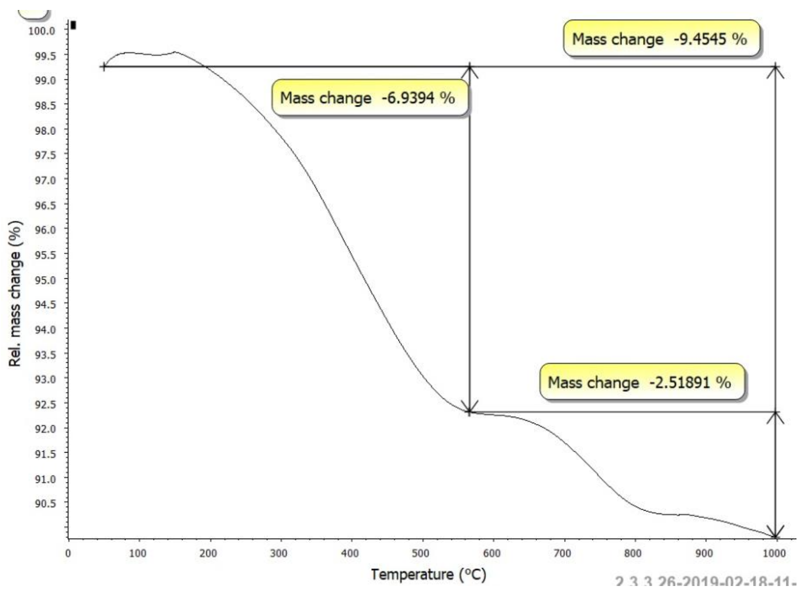


Figure (5) TGA analysis for P1-EP

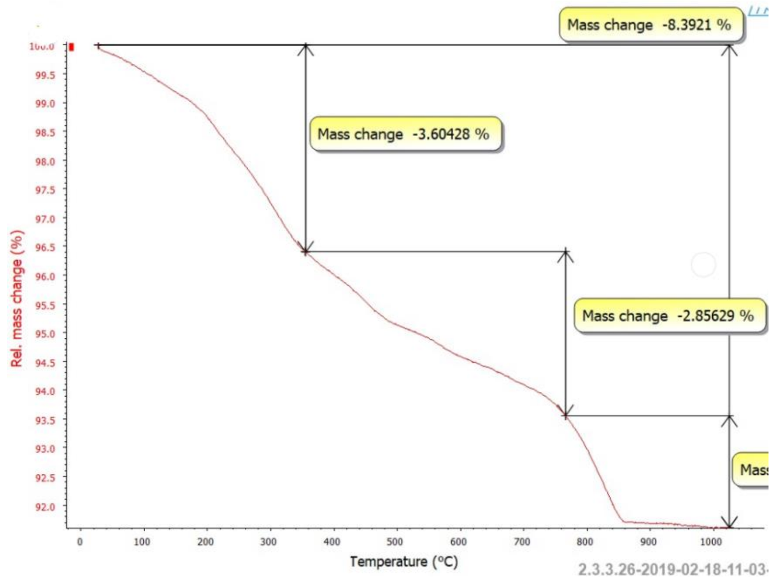


Figure (6) TGA analysis for P2-EP/QP

4.3.Fire resistance

The measured residual compressive strength of the uncoated control concrete specimens and the specimens coated by the 2 studied materials with 2 thicknesses 1 cm and 2 cm are shown in **Table (3)**. The ordinary concrete cubes showed an average compressive strength of 400 kg/cm^2 when tested before heating at room temperature. After burning at 550°C, their average residual compressive strength was 162.33 kg/cm^2 which means that they lost about 60% of their strength. The uncoated concrete specimens completely lost their compressive strength when burned at 850 and 1000°C. This can be attributed to the conversion of the quartz in the siliceous aggregate from α to β form which is accompanied by volume expansion at approximately 573°C, along with the decomposition of the cement components which leads to a complete destruction of the specimens **[15]**.

The concrete cubes were plastered by the 2 studied materials with 2 thicknesses 1 cm and 2 cm. they were placed to the specified temperatures for 2 hours then they were left to cool down at room temperature. The concrete specimens were then extracted from the coating covering them and tested for determining the residual compressive strength.

At 550°C, the specimens coated with P1-EP showed a residual compressive strength of 64% and 78% when coated by 1 cm and 2 cm respectively. While the specimens coated with P2-EP/QP showed a residual compressive strength of 93% and 100% when coated by 1 cm and 2 cm respectively. At 850°C, the specimens coated with P1-EP showed a residual compressive strength of 12% and 19% when coated by 1 cm and 2 cm respectively. While the specimens coated with P2-EP/QP showed a residual compressive strength of 32% and 39% when coated by 1 cm and 2 cm respectively. Both plastering materials increased the residual compressive strength of the concrete specimens, and it can be observed that increasing the coating thickness showed an effective effect on the compressive strength. However, it can be observed that the materials coated with P2-EP/QP where quartz powder is included as a partial replacement of cement showed a higher resistance at elevated temperature than P1-EP. This can be attributed to the partial pozzolanic activity of expanded perlite aggregate and quartz powder with the presence of water vapor which is responsible for increasing the fire resistance of the studied material, along with the porous microstructure of expanded perlite which results in a high water vapor permeability and decrease the internal pore pressure in the studied materials which together maintain the residual compressive strength of the concrete specimens.

At 1000°C, cracks appeared on the surface of both plastering materials which allowed the heat to penetrate to the concrete cubes and loss about 95% of their compressive strength. This is attributed to the degradation of expanded perlite which takes place at approximately 900-1000°C, accompanied by the decomposition of C-S-H phase and $Ca(OH)_2$ in which results from the cement hydration.

Table (3) Residual compressive strength of the specimens

Code	**Temperature (°C)**	**$F_{c,res}$ avg. (kg/cm^2) Coating Thick. = 1cm**	**$F_{c,res}$ avg. (kg/cm^2) Coating Thick. = 2cm**
Control	25	400	
	550	162.33	
	850	16.23	
	1000	16.03	
P1-EP	550	253	313
	850	45.67	76.67
	1000	18.90	22.10
P2-EP/QP	550	372.33	405.50
	850	131	152.25
	1000	28.97	32.50

5. Conclusion

In this case study, 2 coating cement-based materials with expanded perlite as a lightweight aggregate in both materials and quartz powder as a partial replacement of cement in 1 of them were used to evaluate the residual compressive strength of concrete cubes coated with them with variable thicknesses 1 cm and 2 cm. Both materials showed an increase in the residual compressive strength of the concrete specimens due to the porous structure of the expanded perlite which decrease the internal pore pressure and decrease the risk of spalling. However, the inclusion of quartz powder showed approximately no loss in the compressive strength of the concrete specimens at 550°C and higher residual compressive strength at 850°C, this can be attributed to the partial pozzolanic activity of the expanded perlite and quartz powder at elevated temperatures with the existence of water vapor which accelerated the cement hydration and increased the fire resistance. This indicates that the inclusion of quartz powder along with expanded perlite increased the fire resistance of the plastering material and therefore increased the residual compressive strength of the concrete cubes.

6. References

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