Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (40) No. (3) July, 2018

PERFORMANCE OF LIMESTONE CEMENT-GRAPHITE MORTARS

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ملخص البحث :

تمثل انبعاثات ثانى أكسيد الكربون ضررا كبيرا للبيئة، ولذا تتجه التكنولوجيا الحديثة إلى تخفيف هذه الانبعاثات عن طريق استخدام مصادر طاقة بديلة لتلك الملوثة للبيئة مثل استخدام الطاقة الشمسية. وحيث أن تصنيع الأسمنت يمثل 5% من انبعاثات ثانى أكسيد الكربون فإن استخدام مواد أقل استهلاكا للطاقة يؤدى الى تقليل هذه الانبعاثات. ومن ثم يتم استخدام الحجر الجيرى كنسبة من الكلنكر تصل إلى 35% لانتاج أسمنت الحجر الجيرى. وحيث أن مقاومة الضغط لمونة أسمنت الحجر الجيرى قد تتأثر سلبا نتيجة لهذه النسبة من الحجر الجيرى، فمن خلال هذه الدراسة تم استخدام بودرة الجرافيت والتى تعتبر مادة غير ملوثة للبيئة كمادة مالئة فى المونة لتحسين مقاومة الضغط و تقليل مسامية مونة الحجر الجيرى. ونظرا لأن الجرافيت مادة جيدة التوصيل للحرارة فإنه يستخدم فى الخرسانة الموصلة للحرارة مثل تلك المستخدمة فى وحدات تخزين الطاقة فى محطات الطاقة الشمسية. ولمثل هذه الأغراض تم اختبار المونة المكونة من أسمنت الحجر الجيرى والجرافيت تحت تأثير درجات الحرارة العالية. وتم التوصل إلى أن أكبر نسبة جرافيت يمكن استخدامها فى مونة أسمنت الحجر الجيرى بدون تأثير سلبى على مقاومة الضغط هى 8% من وزن الأسمنت وأن أفضل نسبة تؤدى إلى تحسن مقاومة الضغط وتقلل من المسامية مما يحسن التحملها مع الزمن هى 5%.

1. Abstract

Cement industry is one of the primary sources of CO_2 emissions as it consumes large amounts of energy in clinker production. Producing blended cements in order to reduce the amount of clinker using replacement ratios of limestone could save energy to some extent. However, it could affect the compressive strength of the lime stone cement negatively. This paper aimed to use graphite powder which is a non-pollutant material as a filler to enhance the compressive strength and the porosity of the limestone cement mortar. Graphite itself is considered a heat transmission material. Therefore, graphite powder is used in conductive concrete like this in energy storage unites in solar power plants and the more the graphite ratio the more the conductivity of concrete. This concrete could subjected to elevated temperature. Thus, the compressive strength of lime stone cement-graphite mortars was evaluated before and after exposure to elevated temperature. It was found that using graphite powder up to 8% as replacement ratio of cement weight does not affect the compressive strength negatively. The optimum replacement ratio is 5% which enhance the compressive strength and decrease the porosity of the mortars.

Keywords: Limestone cement, Graphite Powder, Compressive strength, Durability.

2. Introduction

Decreasing carbon footprint is a major requirement for green environment. When fossil fuels are burned they emit harmful gases that are the primary cause of air pollution and global warming. Thus, the technologies have to decrease the causes of CO_2 emissions in different industries and resort to the sustainable energy sources. In this aspect, solar thermal power is considered one of the most attractive methods to produce electricity hardly with any polluting or carbon dioxide emissions.

Cement industry accounts for around 5% of global carbon dioxide (CO_2) emissions. Recently, utilization of blended cements is usually preferred due to their significant contribution to sustainable construction. Blended cements have the ability of decreasing CO2 emissions by reducing clinker production in plants. These cements can also be used to help achieve Leadership in Energy and Environmental Design (LEED) points.

Regular portland cement may contain up to 5% limestone. According to the European Standard EN 197-1, the production of blended cements incorporating limestone as major additive increased in CEM II cements such as CEM II/A-L contain between 6% and 20% limestone while CEM II/B-L contain between 21% and 35% limestone.

Limestone powder is not reactive. However, the percentage and fineness of limestone powder affect the cement hydration by three main effects: a) improving packing by wider dispersion of cement grains, b) increasing solid surface area, and c) increasing effective w/c ratio which increases porosity and decreases strength. The strength of concrete produced with limestone cement is strongly influenced by the quality of the limestone used, the manufacturing process (blending versus intergrinding) and the final particle size distribution of the cement [1]. Addition of up to 10% limestone does not significantly alter the compressive strength while further increase of the lime stone up to 35% decrease the compressive strength[2].

Using filler material could decrease the porosity of the cement mortar and compensate the loss of the compressive strength. In the aspect of friendly energy sources, graphite is a wide material source and has no pollution to environment [3]. Graphite powder has established its imprint in the concrete production as a conductive filler in specific applications such as, roadway de-icing, electrical grounding, radiant heating, steel reinforcement corrosion protection, structural health monitoring, solar thermal power plants, fuel cells, electromagnetic shielding, heat-harvesting technology [4-10]. Based on the literature, using graphite powder can increase the conductivity in cement-based mortars while the compressive strength is decreased at a certain ratio of graphite. [5-6].

3. RESEARCH SIGNIFICANCE

In this research, ordinary Portland cement–graphite and limestone cement- graphite mortars with different graphite replacement ratios were produced. Experimental data on the mortars compressive strength is evaluated before and after exposure to elevated temperature. The main target is to determine the optimum graphite ratio from the strength point of view and durability with meaning of water absorption.

4. EXPERIMENTAL PROGRAM

4.1 Materials

Two series of mortar mixtures were prepared. Every series include 7 different mixtures with different graphite ratios. Two cement types compatible with EN 197-1 were used in the two series of the prepared mortars. Cement CEM I 32.5N was used in the first series and limestone cement CEM II/B-L32.5N was used in the second series. Black graphite powder with a purity 99.5% was used. The XRD pattern of the graphite powder is declared in Fig.1.

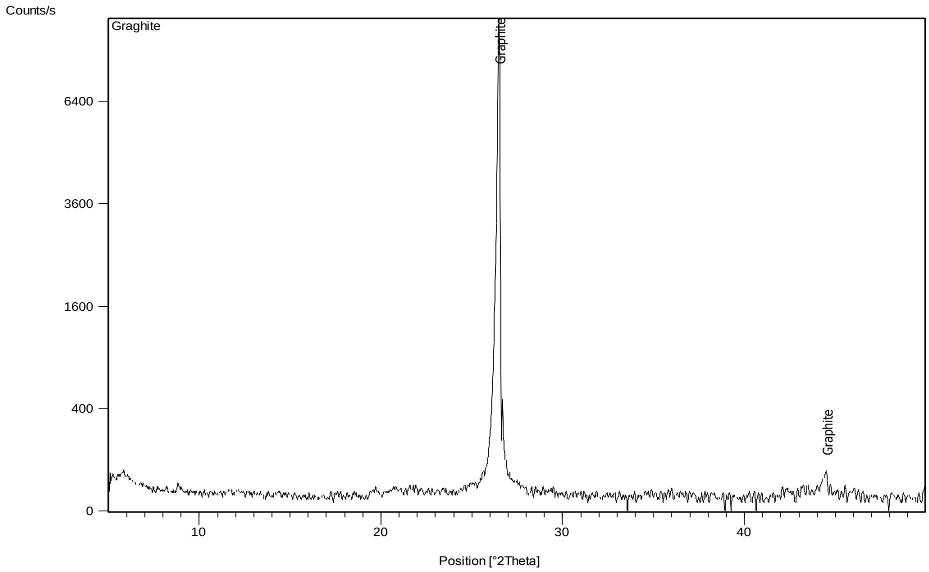


Fig. 1. Graphite XRD pattern

4.2 Preparation and testing of specimens

Standard mortar mixtures, (cement: sand: water of 1:3:0.5 by weight), were prepared. The graphite powder was employed in amounts of 0, 2, 4, 5, 6, 8 and 10% by mass of cement. Twelve standard prismatic specimens of 40x40x160 mm have been prepared for every mixture. All specimens were kept at standard curing conditions for 28 days.

Compressive strength of nine prisms of each mixture were tested; three prisms were tested before heating , three prisms were heat-treated in furnace at 300^{o}C for 2 h and three prisms were heat-treated in furnace at 600^{o}C for 2 h. The three specimens of each mixture were tested according to EN 196-1 standard, the specimens were tested under flexure then the prism halves were tested under compression , and then their mean values were calculated as the ultimate compressive strength. For each specimen, testing was conducted until the sample failed.

Absorption rate for the prepared mortars was measured by drying three prisms in oven at 100^{o}C until constant mass then submerged in water for 24h.

5. Results and Discussion

Compressive strength of mortars before heat treating are shown in Figure 2. Comparing test results of mortars with non-graphite, a marginal decrease in compressive strength in limestone cement CEM II/B-L mixture is seen. This is expected as a result of the dilution (reduction of cement clinker and consequently reduction of the hydration products).

Mortars with CEM II cement showed improvement in compressive strength by increasing graphite content up to 8% where graphite powder was effective physical filler. The optimum graphite replacement ratio was 5%, which improved the mortar compressive strength by 15% comparing with that without graphite. However, increasing graphite content to 10% affect the compressive strength negatively that because graphite powder could not sustain the pressure which the hydration products of cement could sustain. That was the reason of compressive strength reduction in CEM I mortars as long as graphite content increased.

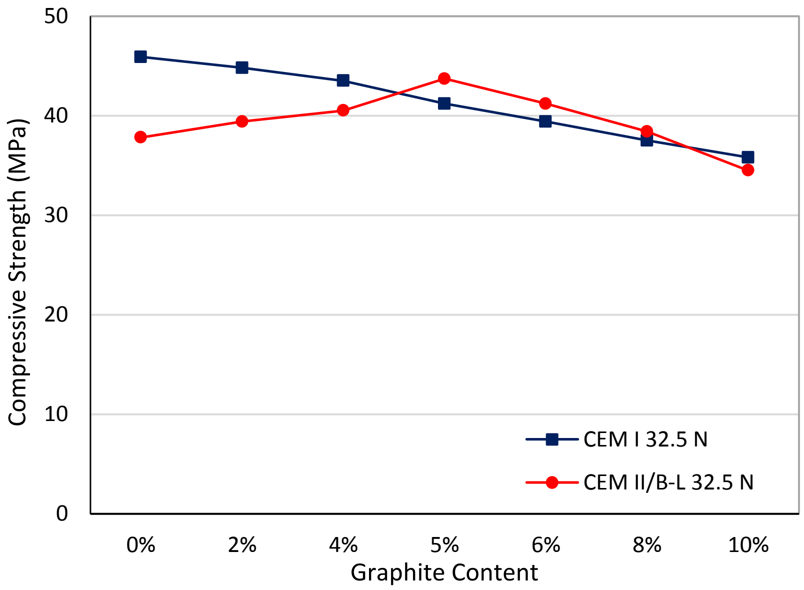


Figure 2: Effect of graphite content on different cement types

Figures 3 and 4 show the reduction of mortars compressive strength at elevated temperature indicating that the variation trend of compressive strength before heating is similar to that after heating.

At temperature of 300^{0}C, mortars had a reduction in compressive strength ranged from 15 to 19 % for CEM I mortars and from 8 to 15 % for CEM II mortars. At this region of temperature the chemically bound water starts to evaporate, which in turn decreases the compressive strength of concrete. It was observed that non graphite mortars showed the same strength reduction ratios of about 15% while with the increase of graphite ratio the strength reduction in CEM II mortars was smaller than that of CEM I comparable mortars.

At about 600^{0}C, all mortars were deteriorated and almost completely dehydrated. That is attributed to the $Ca(OH)_2$ decomposition (i.e., $Ca(OH)_2 \rightarrow CaO + H_2O$) at that region of temperature [11]. The reduction in compressive strength ranged from 35 to 40% for the two type of mortars.

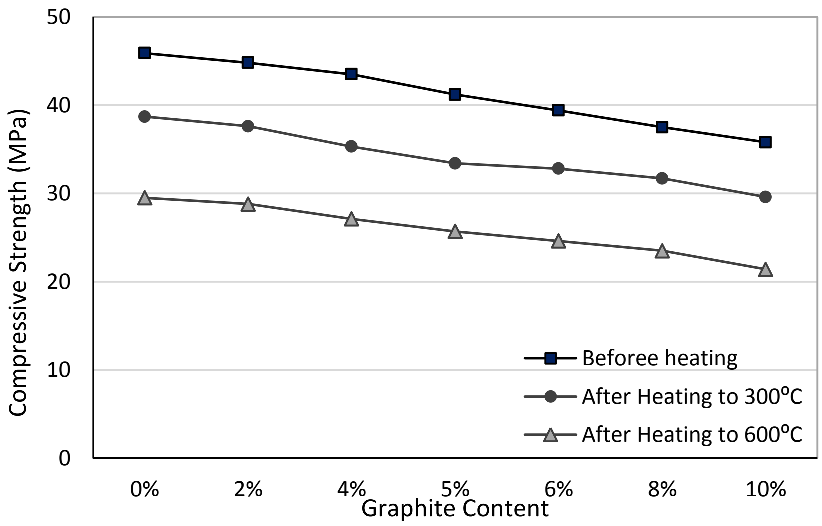


Figure 3: Effect of graphite content and heat treatment on compressive strength of CEM I 32.5 N mortar

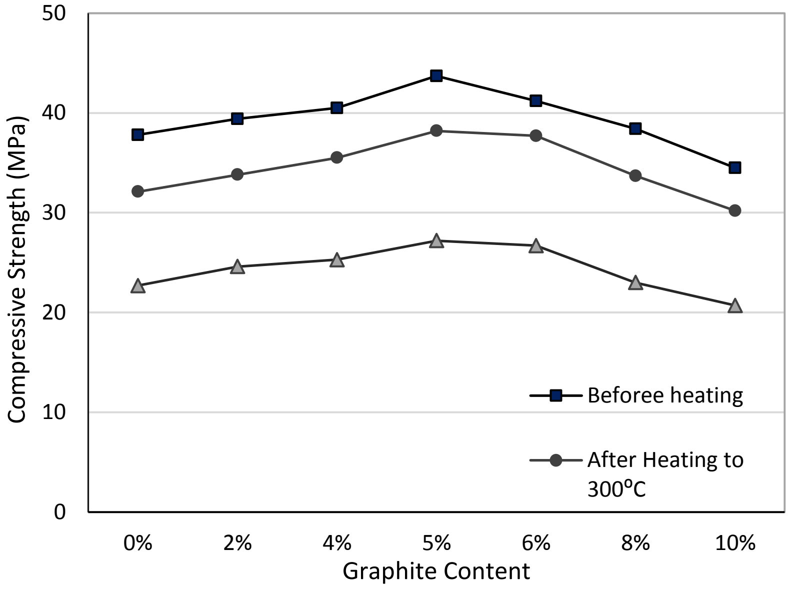


Figure 4: Effect of graphite content and heat treatment on compressive strength of CEM II/B-L 32.5 N mortar

Water absorption is normally used as a durability index of the concrete. As shown in Figure 5, increasing of graphite powder content reduced the water absorption of the two types of mortars. This is attributed to the fact that incorporating graphite powder which is very fine material reduced the air content of the mixtures and acted as microfilling material which in turn reduced the pores connectivity [12]. Since CEM II mortars have more pores than that of the CEM I, the graphite powder content up to 10% showed reduction of water absorption of 45% and 54% in CEM I and CEM II mortars, respectively.

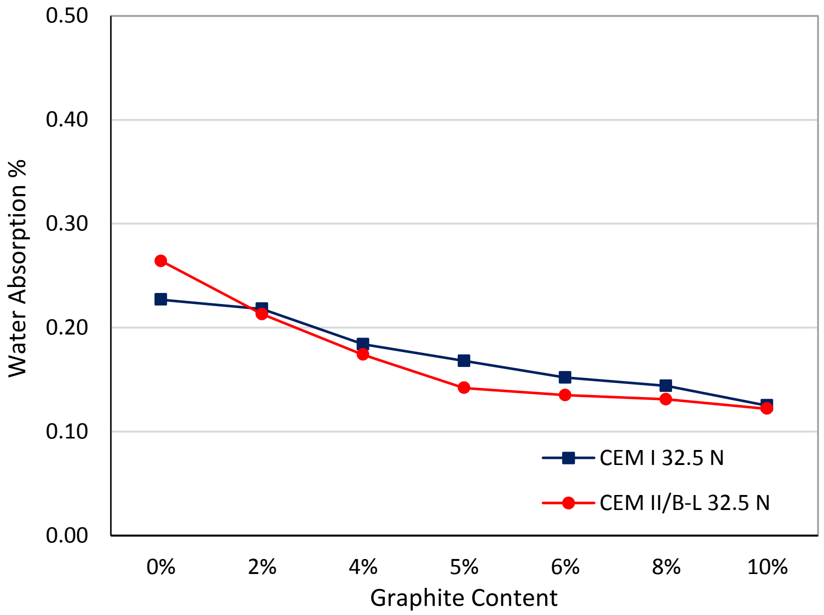
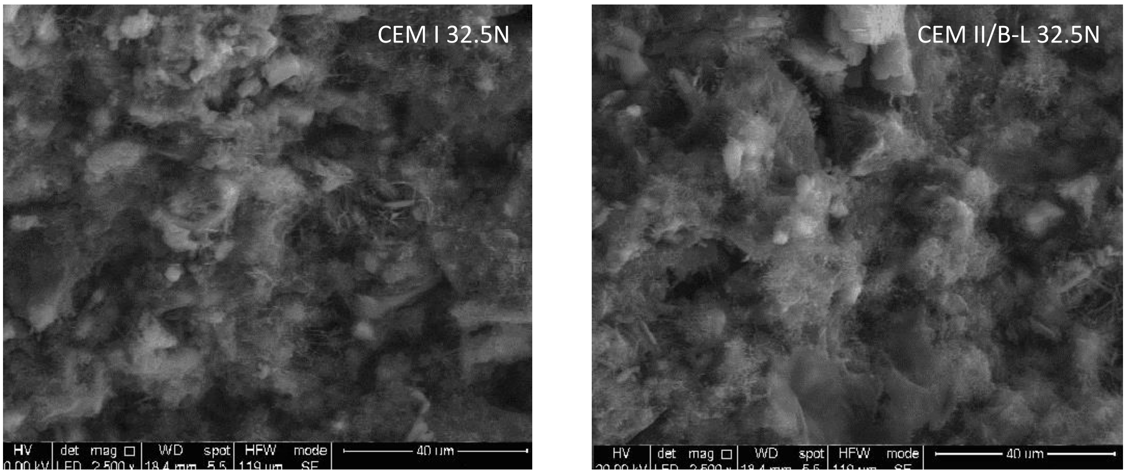


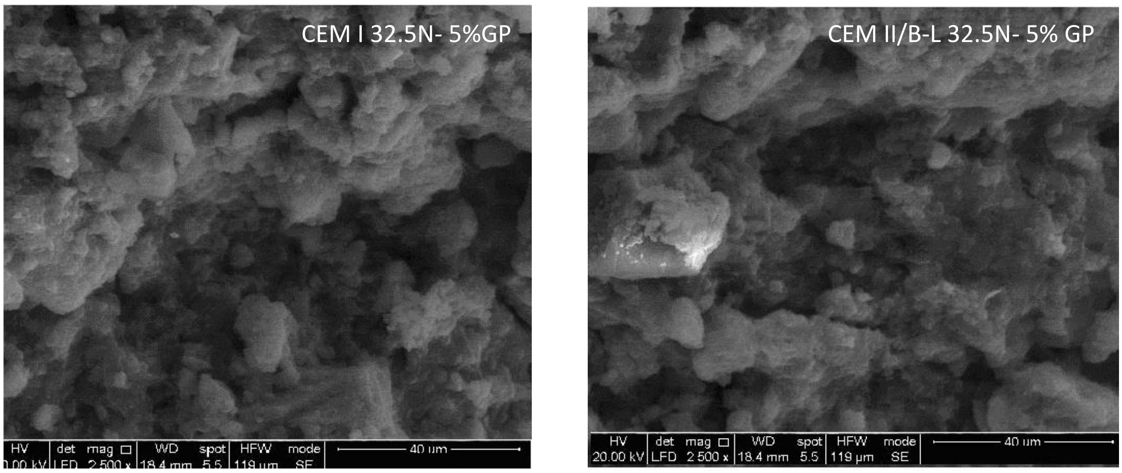
Figure 5: Effect of graphite content on water absorption

Figures 6(a and b) show the SEM of cement paste of CEM I and CEM II respectively, it can be seen that C-S-H gel independently formed, mutually linked needle-shaped hydrates (ettringite), and many $Ca(OH)_2$ crystals, showing a sparse internal structure with non-crystal hydrates. Some voids can be clearly observed inside the specimens which increased in CEM II specimen. Figures 7(a and b) show the SEM of composite cement paste with graphite at 5% replacement of CEM I and CEM II respectively, where the graphite seems layered-like. It can be seen that graphite is distributed homogeneously in the cement matrix, and the microstructure become more denser, It can be clearly observed that there are many cement hydration products adhering to the surface of the graphite. This indicates that high bonding strength between graphite and cement matrix is achieved.



a. CEM I 32.5 N mortar **b. CEM II/B-L 32.5 N mortar**

Figure 6. SEM micrographs of the fracture sections of non-graphite mortars



a. CEM I 32.5 N-5% GP mortar **b. CEM II/B-L 32.5 N -5% GP mortar**

Figure 7. SEM micrographs of the fracture sections of 5% graphite mortars

6. CONCLUSIONS

Performance of ordinary and limestone cement mortars with different replacement ratios of graphite powder were investigated in this paper. It could be concluded that:

1- Compressive strength of ordinary cement mortars decreased with the addition of graphite.

2- graphite powder up to 8% increase the compressive strength of limestone cement mortars.

3- Optimum value of graphite powder as are placement value from limestone cement is 5%.

4- Graphite powder enhances the durability of cement mortars since it acts as a microfiller to fill the pores of the cement mortars effectively.

7. REFERENCE

1. Hooton, R. D., Nokken, M., and Thomas, M. D. A., 2007, "Portland-Limestone Cements: State-of-the-Art Report and Gap Analysis for CSA A 3000" University of Toronto, June 17.
2. Tsivilis, S., Chaniotakis, E., Kakali, G. and Batis, G., 2002, "An analysis of the properties of Portland limestone cements and concrete" Journal of Cement & Concrete Composites V.24, pp.371–378.
3. Xin Tian, Hu Hu anf Bin Chen, 2012, "An Environment-Friendly Conductive Concrete" Earth Science Research; Vol. 1, No. 2, pp185-188.
4. Miguel-Ángel Climent, Jesús Carmona and Pedro Garcés, 2016, "Graphite–Cement Paste: A New Coating of Reinforced Concrete Structural Elements for the Application of Electrochemical Anti-Corrosion Treatments" Journal of Coatings, Vol. 6, Issue3, No. 32.
5. Kraisit Loamrat, Manote Sappakittipakorn, Piti Sukontasukkul, Nemkumar Banthia, 2014, " Effect of Carbon Fiber and Graphite Powder on Resistivity of Cement-based Sensor under Compression" KMUTNB: International Journal of Applied Science and Technology, IJAST, Vol.7, No.1, pp. 29-35.
6. Hui-Wen Yuan, Chun-Hua Lu, Zhong-Zi Xu, Ya-Ru Ni, Xiang-Hui Lan, 2012, " Mechanical and thermal properties of cement composite graphite for solar thermal storage materials" Jpournal of Solar Energy, Vol. 86, pp.3227–3233.
7. Shen Chunhui, Pan Mu, Wu Qiong, Yuan Runzhang, 2006, "Performance of an aluminate cement /graphite conductive composite bipolar plate"Journal of Power Sources, Vol. 159, pp.1078–1083.
8. Shen Chunhui, Pan Mu, Hua Zhoufa, Yuan Runzhang, 2007, "Aluminate cement/graphite conductive composite bipolar plate for proton exchange membrane fuel cells" Journal of Power Sources, Vol. 166, pp.419–423.
9. Jingyao Cao, D.D.L. Chung, 2003, "Colloidal graphite as an admixture in cement and as a coating on cement for electromagnetic interference shielding" Journal of Cement and Concrete Research, Vol. 33, pp.1737–1740.
10. Jian Wei, Lili Zhao, Qian Zhang, Zhengbo Nie, Lei Hao, 2018, "Enhanced thermoelectric properties of cement-based composites with expanded graphite for climate adaptation and large-scale energy harvesting" Journal of Energy and Buildings, Vol. 159 , pp.66–74.
11. T. Z. Harmathy, 1970, “Thermal Properties of Concrete at Elevated Temperatures,” Journal of Materials 5, pp47–74.
12. Amr S. El-Dieba, Mahmoud A. El-Ghareebb, Mohamed A.H. Abdel-Rahmanc, El Sayed A. Nasrd, 2018, " Multifunctional electrically conductive concrete using different fillers", Journal of Building Engineering 15 (2018) 61–69